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Environmental management — Water footprint — Illustrative examples on how to apply ISO 14046

Management environnemental — Empreinte eau — Exemples illustrant l'application de l'ISO 14046

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Contents

Page

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

The committee responsible for this document is Technical Committee ISO/TC 207, *Environmental management*, Subcommittee SC 5, *Life cycle assessment*.

Introduction

Principles, requirements and guidelines for the quantification and reporting of a water footprint are given in ISO 14046. The water footprint assessment according to ISO 14046 can be conducted as a stand-alone assessment, where only impacts related to water are assessed, or as part of a life cycle assessment. In addition, a variety of modelling choices and approaches are possible depending on the goal and scope of the assessment. The water footprint can be reported as a single value or as a profile of impact category indicator results.

This document provides illustrative examples on the application of ISO 14046 to further enhance understanding of ISO 14046 and to facilitate its widespread application.

At the time of the publication of this document, water footprint assessment methods are developing rapidly. Practitioners are encouraged to be aware of the latest developments when undertaking water footprint studies.

These examples are for illustrative purposes only and some of the data used are fictitious. The data are not intended be used outside of the context of this document.

The Bibliography might contain references to methods that are not fully compliant with ISO 14046:2014.

Environmental management — Water footprint — Illustrative examples on how to apply ISO 14046

1 Scope

This document provides illustrative examples of how to apply ISO 14046, in order to assess the water footprint of products, processes and organizations based on life cycle assessment.

The examples are presented to demonstrate particular aspects of the application of ISO 14046 and therefore do not present all of the details of an entire water footprint study report as required by ISO 14046.

NOTE The examples are presented as different ways of applying ISO 14046 and do not preclude alternative ways of calculating the water footprint, provided they are in accordance with ISO 14046.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 14046:2014, *Environmental management — Water footprint — Principles, requirements and guidelines*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 14046:2014 apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at http://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

4 Symbols and abbreviated terms

4.1 Symbols

α	characterization factor
C	concentration
E	emission
F	footprint
R	rainfall
V	volume

4.2 Abbreviated terms

1,4-DB 1,4-Dichlorobenzene

2,4-D 2,4-Dichlorophenoxyacetic acid

APSIM Agricultural Production Systems sIMulator

BOD Biological Oxygen Demand (BOD5 means "measured during 5 days")

CF Characterization Factor

COD Chemical Oxygen Demand

CTU Comparative Toxic Unit

NOTE 1 "CTU_e" for ecosystems; "CTU_h" for humans; "CTU_c" for cancer; "CTU_{n-c}" for non-cancer.

CWU Consumptive Water Use

CWV Critical Water Volume

DALY Disability Adjusted Life Years

DWU Degradative Water Use

DWCM-AgWU Distributed Water Circulation Model Incorporating Agricultural Water Use

ET Evapotranspiration

FU Functional Unit

H_2O-eq Water "equivalent"

NOTE 2 Typical unit to express the impact score associated with water scarcity. Sometimes the term H_2O-eq is written H_2O eq, or H_2Oe.

LCA Life Cycle Assessment

LCI Life Cycle Inventory

LCIA Life Cycle Impact Assessment

OEF Organization Environmental Footprint

PEF Product Environmental Footprint

PDF Potentially Disappeared Fraction of species

PAF Potentially Affected Fraction of species

RU Reporting Unit

TOC Total Organic Carbon

WSI Water Scarcity Index

NOTE 3 Sometimes the term water stress index (also abbreviated as WSI) is used in the literature for what is termed a water scarcity index in this document.

WSF Water Scarcity Footprint

WULCA Water Use in LCA

5 Selection of the type of water footprint assessment

5.1 General

The water footprint assessment conducted according to ISO 14046 can be:

— a stand-alone assessment where only impacts related to water are assessed;

— a part of a life cycle assessment (LCA) where consideration is given to a comprehensive set of environmental impacts, which are not only impacts related to water.

Table 1 lists the illustrative examples in this document and the different topics that are highlighted in each example.

Table 1 — Types of water footprint assessment shown in the examples

Example	Product/ process or organization focus	Topic highlighted [a]	Case study used in the example	Type of footprint [a]	System boundary	Impact assessment method [a]
A	Product/ Process	Water footprint inventory	Power plant	n/a (Water footprint inventory only)	Gate-to-gate	n/a (inventory only)
B	Product/ Process	Water footprint inventory using a baseline	Rice cultivation	n/a (Water footprint inventory only)	Gate-to-gate	n/a (inventory only)
C	Product/ Process	Option comparison using scarcity	Municipal water management	Water scarcity footprint	Gate-to-gate	Boulay et al. (2016) (WU LCA)[5]
D	Product/ Process	Application of water scarcity footprint method	Rice	Water scarcity footprint	Gate-to-gate	Ridoutt and Pfister (2010) [6]
E	Product/ Process	Influence of impact assessment method chosen for scarcity	Textile	Water scarcity footprint	Cradle-to-grave	Boulay et al. (2016) (WULCA) [5]; Pfister et al. (2009)[7]; Frischknecht et al. (2008) [8]; EU (2013) (PEF/OEF)[9]; Boulay et al. (2011a)[10]; Hoekstra et al. (2012) (Water Footprint Network - WFN) [11]; Berger et al. (2014)[12]

a All examples explicitly or implicitly contain a water footprint inventory.

Table 1 *(continued)*

Example	Product/ process or organization focus	Topic highlighted [a]	Case study used in the example	Type of footprint [a]	System boundary	Impact assessment method [a]
F	Product/ Process	Seasonality	Reservoir operation	Water scarcity footprint	Gate-to-gate	Pfister and Bayer (2014) [13]
G	Product/ Process	Scarcity vs availability	Packaging production	Water scarcity footprint; water availability footprint	Gate-to-gate	Boulay et al. (2011a)[10]
H	Product/ Process	Influence of water sources	Wheat cultivation	Water scarcity footprint	Gate-to-gate	Yano et al. (2015)[14]
I	Product/ Process	Influence of forest management / land use change	Beer production	Water scarcity footprint	Gate-to-gate	Yano et al. (2015)[14]
J	Product/ Process	Number of indicators per type of impact	Maize	Water eutrophication footprint	Cradle-to-gate	EU (2013) (PEF/OEF)[9]; Jolliet et al. (2003) (IMPACT 2002+) [15]
K	Product/ Process	Comprehensive water footprint	Packaging product	Water footprint (comprehensive profile)	Cradle-to-gate	Bulle et al. (2016) (IMPACT World+)[16]; Rosenbaum et al. (2008) (USEtox)[17]; Guinée et al. 2001[19]; EU (2013) (PEF/OEF) [9]; Verones et al. (2011) [19]; Boulay et al. (2016) (WULCA)[5]; Boulay et al. (2011a)[9]; Hannafiah et al. (2011)[20]
L	Product/ Process	Applying weighting to obtain a single value	Cereal cultivation	Non-comprehensive weighted water footprint	Gate-to-gate	Goedkoop et al. (2009) (ReCiPe)[21]; Ridoutt and Pfister (2010) [6]; Ridoutt and Pfister (2013)[22]

[a] All examples explicitly or implicitly contain a water footprint inventory.

Table 1 *(continued)*

Example	Product/ process or organization focus	Topic highlighted [a]	Case study used in the example	Type of footprint [a]	System boundary	Impact assessment method [a]
M	Product/ Process	Water footprint as part of an LCA	Packaging product	Water footprint as part of an LCA	Cradle-to-gate	Boulay et al. (2016) (WULCA)[5] (Water degradation footprint profile already present)
N	Product/ Process	Seasonality	Textile product	Non-comprehensive water footprint	Cradle-to-gate	Hoekstra et al. (2012); (Water Footprint Network - WFN)[11]
O	Product/ Process	Applying weighting to obtain to single value	Municipal water management	Non-comprehensive weighted water footprint	Cradle-to-grave	Pfister et al. (2009)[7]; Ridoutt and Pfister (2013) [22]; Goedkoop et al., (2009) (ReCiPe) [21]; Jolliet et al. (2003) (IMPACT 2002+)[15]; Rosenbaum et al. (2008) (USEtox)[17]
P	Organization	Applying water footprint to different sites	Chemical production	Non-comprehensive water footprint	Gate-to-gate	Berger et al. (2014)[12]; Saling et al. (2002)[23]
Q	Organization	Applying water footprint to supply chain of a company	Aluminium production	Water scarcity footprint	Cradle-to-gate	Pfister et al. (2009)[7]
R	Organization	Applying water footprint to a service company	Hotel operation	Non-comprehensive water footprint	Gate-to-gate	Boulay et al. (2016) (WULCA)[5] at the monthly approach; Goedkoop et al. (2009) (ReCiPe)[21]

a All examples explicitly or implicitly contain a water footprint inventory.

NOTE 1 Guidance about application of LCA to organizations is given in ISO/TS 14072. In addition, ISO 14046:2014, Annex A, provides guidelines for water footprint assessment of organizations.

NOTE 2 The principles of comprehensiveness for an LCA study and for a water footprint assessment are different (see ISO 14040:2006, 4.1.7, and ISO 14046:2014, 4.13).

NOTE 3 The term “partial” is sometimes used as a synonym for “non-comprehensive”. However, “partial” is avoided in this document as it is also used with a different meaning, such as in ISO/TS 14067.

5.2 Choice of the type of water footprint study

The different types of water footprint are defined in ISO 14046:2014, 5.4.5 to 5.4.7. The choice of a particular type of water footprint to be assessed in a stand-alone water footprint study is determined in the goal and scope definition phase.

In addition to the goal of the study (see ISO 14046:2014, 5.2.1) the choice of type of water footprint may be influenced by consideration of an appropriate system boundary, the type(s) of water resource used and affected water resources, the associated changes in water quantity and quality and determination of relevant impact assessment categories and methodologies.

Figure 1 illustrates a procedure for choosing the type of water footprint for a stand-alone water footprint study.

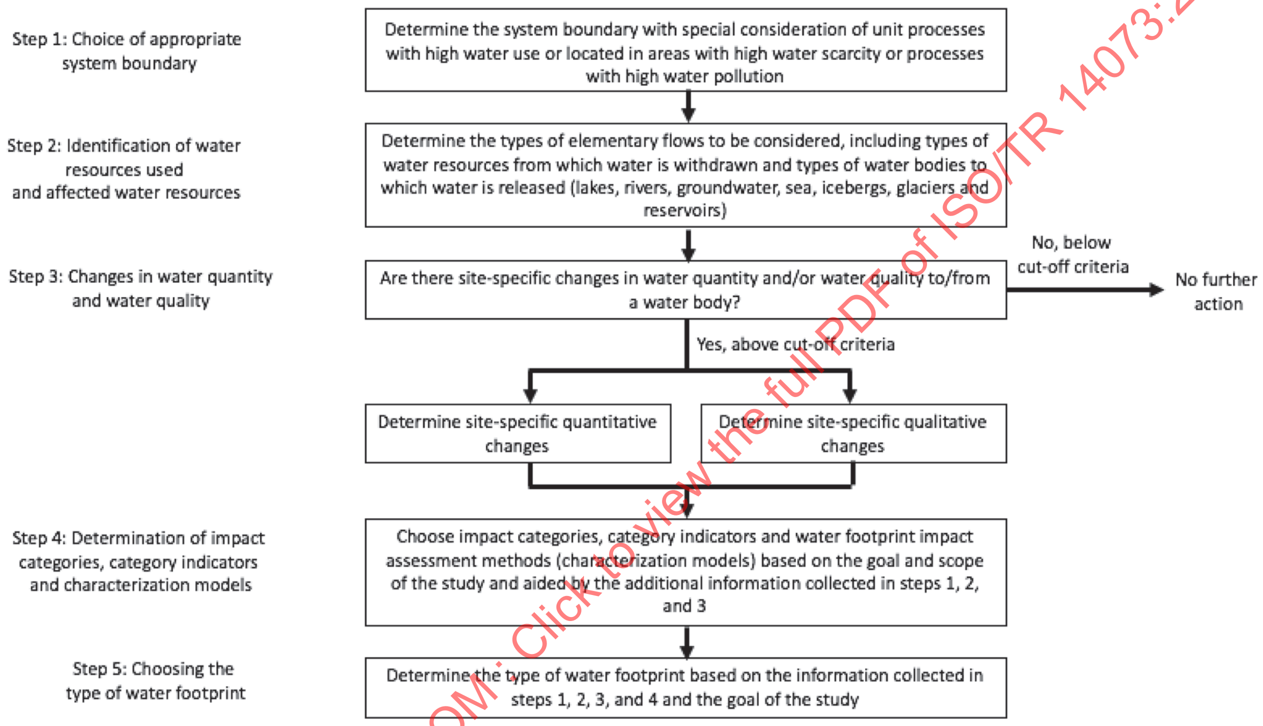


Figure 1 — Procedure for choosing the type of a water footprint assessment for a stand-alone water footprint study

The procedure for choosing an appropriate system boundary in a water footprint study as defined in ISO 14046:2014, 3.3.8, can be supported by collation of additional information such as:

— developing a map showing the geographical location of each unit process;

— identification of the unit processes that are located in areas of critical water availability (taking into account relevant seasonal and temporal variability);

— identification of the unit processes with air, water and soil emissions that can potentially affect ecologically vulnerable water bodies.

All water inputs and outputs relevant to the system (see examples in Figure 2) are considered for relevant changes in water quantity (volume) and water quality parameters and/or characteristics, including emissions to air, water and soil that affect water quality. Estimates may be based on readily available data or models.

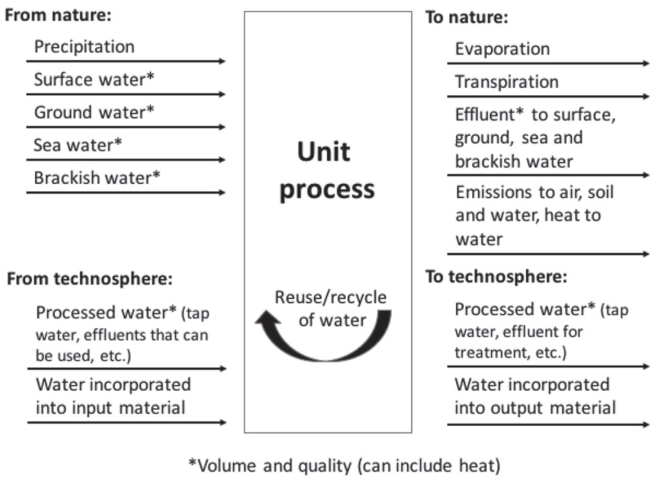


Figure 2 — Examples of water inputs (left) and outputs (right) for a unit process under study

In addition to the goal of the water footprint study, the information collected in order to define the system boundary, the type(s) of water resource used and affected water resources, and the associated (quantitative and/or qualitative) changes in water, can assist in determining the appropriate impact categories, category indicators and the characterization models to be considered for the water footprint study – and therefore choice of a type of water footprint. Based on the information collected, it is possible to:

— estimate the degree of likely significance (i.e. potential contribution to the water footprint) of each unit process for the study, and therefore which unit processes should become the focus for more detailed data collection;

— specify the data requirements (e.g. primary data, secondary data, estimated data) based on the likely significance of each unit process for the water footprint;

— define the initial cut-off criteria for the study (which are revisited throughout the study following ISO 14046:2014, 4.5).

Based on this information and general information related to the goal of the study (see ISO 14046:2014, 5.2.1) the type of water footprint that will be a result of the water footprint study can be chosen.

6 Presentation of the examples

6.1 Example A – Water footprint inventory of two power plants

6.1.1 Goal and scope

This example illustrates the compilation of water flows and emissions affecting water of a unit process.

A utility wanting to evaluate which of two planned options has the lowest direct water footprint starts by creating the direct water footprint inventory of both options, from a gate-to-gate perspective. This direct water footprint inventory can then be used in combination with water footprint impact assessment methods, considering water scarcity footprint and/or water degradation footprint, to evaluate the direct water footprint of both options.

NOTE The term “direct” is used as “what happens on the site” (see ISO 14046:2014, 3.5.14) (gate-to-gate, excluding any inputs such as infrastructure production, maintenance and outputs such as electricity). The term “indirect” is used for background processes (see ISO 14046:2014, 3.5.15).

6.1.2 Inventory

Table 2 shows the water footprint inventory associated with both options. The inventory is based on collected and modelled data and expressed per kWh of electricity produced.

Table 2 — Gate-to-gate water footprint inventory associated with two power plants options

Flows	Unit (per kWh produced)	Option 1 (power plant, situated in a location A, using through flow without cooling tower)	Option 2 (power plant, situated in a location B, with lower river flow and therefore using a cooling tower)
Address of the power plant	—	AA	BB
Location	—	Location A (name of the country and if possible drainage basin)	Location B (name of the country and if possible drainage basin)
Temporal variation	—	Assumed to be a constant use of water	Assumed to be a constant use of water
Water withdrawal	l	40	10
Water release	l	38	6
Temperature of water released	°C	25	25
Water consumed	l	2	4
Chromium (III) emitted to water	g	0,001	0,001
Oil emitted to water	g	0,02	0,02
SO_2 emitted to air	g	0,7	0,7
NO_x emitted to air	g	0,6	0,6
Mercury emitted to air	mg	0,04	0,04
Dioxin, 2,3,7,8, Tetrachlorodibenzo-p-	ng	0,07	0,07
More if available	...	...	...

6.1.3 Interpretation

Such an inventory can be as extensive as needed to capture all emissions (as well as other information) useful to apply the impact assessment methods that will be chosen in the study. The quality of the data is sometimes specified in order to provide information about the accuracy of the water footprint that will be calculated based on this inventory. The naming of the flows in the inventory is matched with the naming of the flows in the impact assessment.

From the address of the power plants, the data of the location (e.g. the water scarcity index) can be determined within a subsequent impact assessment using satellite imagery. As the water scarcity footprint of both locations can be very different, comparison between both options on the inventory level can be misleading.

6.2 Example B - Water footprint inventory of rice cultivation

6.2.1 Goal and scope

This example illustrates calculation of water flows based on the hydrology of an area.

This example is not a traditional LCA case study, but it illustrates a special case, considering non-irrigated paddies as the baseline.

The example is shown as an exercise of a non-comprehensive water footprint inventory by utilizing existing hydrological knowledge, namely the usage of a hydrological model to analyse water footprint inventory of unit processes.

This example refers to rice cultivation, as an example of a water footprint inventory analysis, in a country in monsoon Asia with moderate rainfall and suitable rice cultivation practices. An irrigated area lies downstream of the intake facility (Figure 3) and the baseline land use is rainfed (i.e. non-irrigated) rice.

This is a “gate-to-gate” example. For the purpose of this example, energy and goods required for rice cultivation are excluded.

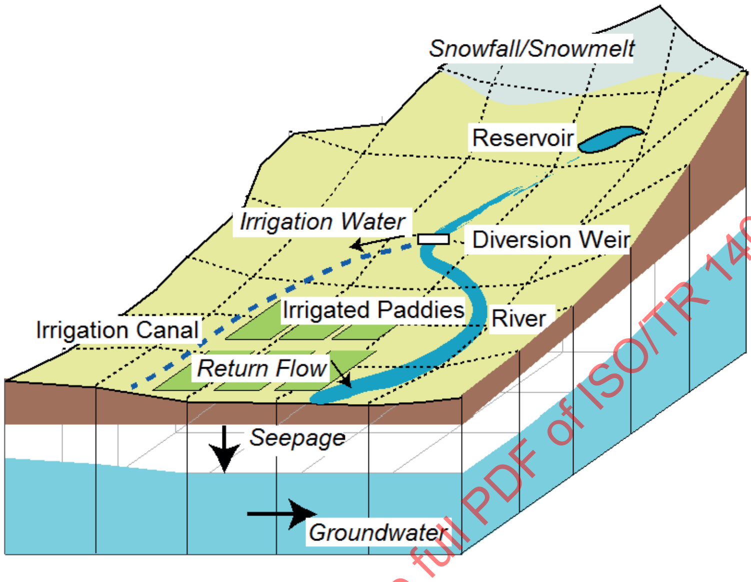


Figure 3 — Depiction of basin-wide processes

6.2.2 Inventory

The elementary flows are quantified by utilizing a hydrological model, such as DWCM-AgWU (Yoshida et al. 2012[24]; Masumoto et al. 2009[25]), at the scale of drainage basins. Agricultural situations typically require modelling because it is difficult, or even impossible, to measure all the elementary flows.

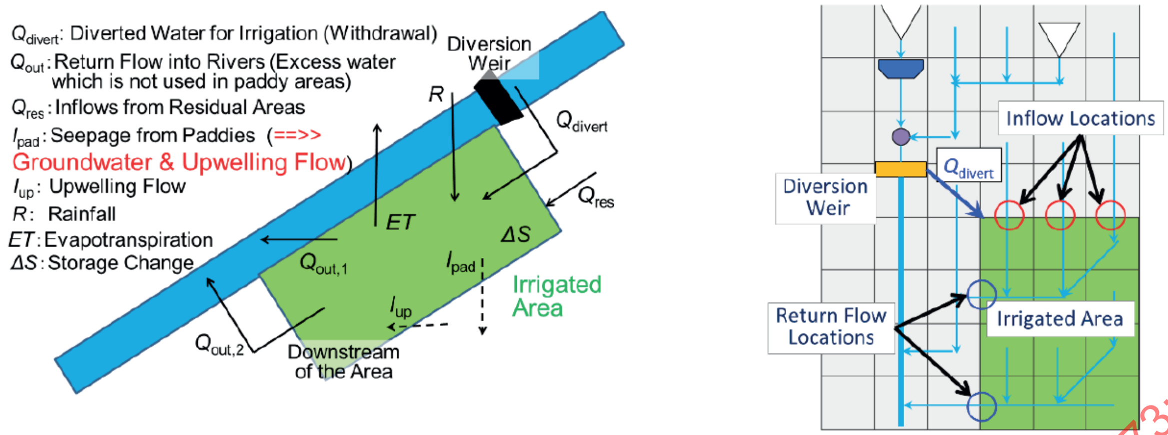
The elementary flows quantified in the water footprint inventory can be used to determine the water scarcity footprint which is described in other examples. In order to determine the water availability footprint, the water degradation footprint or a water footprint profile, other elementary flows related to water quality need to be determined.

6.2.2.1 Elementary flows

In this approach, a single process in an agricultural area receives rainfall, irrigation and residual water (water that has not been diverted from the river for the intention to irrigate this area; inflow locations) as inputs, and have evaporation, transpiration, percolation to groundwater and return flow to the river as outputs (Figure 4).

Furthermore, it is shown that all input water is withdrawn from the location of the process and all output water is released to the location of the process. Part of water output as groundwater gradually returns back into the river systems or is utilized as the source of public water supply.

In paddy areas, the source of freshwater differs between rainfed (precipitation) and irrigated paddies (irrigation water). In both cases, various types of water use exist, such as three types in rainfed agriculture (only rainfall, rainfall plus supplementary water stored in small ponds, and using flooding water) and six categories in irrigated paddies (gravity-fed water, pumped water, reservoirs, impounding of silty water (colmatage), release of river water into coastal wetlands and near-shore waters by managing controlling tides, and groundwater).



NOTE 1 Upwelling flow is defined as part of seepage returning to the surface from the ground within an irrigated area.

NOTE 2 The irrigated area is delineated for the DWCM-AgWU.

a) **Water balance** b) **Inflow and outflows in an irrigated area**

Figure 4 — Schematics of the calculation for hydrological components and river return ratio

6.2.2.2 Calculation procedure of water footprint inventory

The water footprint inventory is determined as follows:

a) the estimation in water footprint inventory of unit process for rice cultivation in paddy areas is carried out at the scale of the irrigated area;

b) each elementary flow is modelled using DWCM-AgWU, which comprises water allocation and management, evapotranspiration, planting time/area (rice phenology), paddy water use and runoff models (Yoshida et al. 2012[24]; Masumoto et al. 2009[25]);

c) the water balance of the baseline situation is calculated assuming no irrigation is carried out.

NOTE In the paddy-dominant areas with two or three crops within a year, paddies are classified into rainfed in rainy seasons and irrigated in dry season. As for the baseline situation, it is assumed that an irrigation system is not introduced, so paddies are regarded as rainfed types.

These results are then summed across the basin (an example in one region of the basin; Table 3) and expressed in the units m^3 per ha per irrigation period, or m^3 per kg brown rice for example.

6.2.2.3 Input parameters and calculated results of unit processes

Input parameters into the DWCM-AgWU model are land use data, meteorological data, geological and geomorphologic data, and celled basin data. The model estimates the planting area of paddies, intake amount and soil moisture at arbitrary locations in the basin. The model is validated against observed values of discharges of rivers and is shown to provide reliable estimates in the absence of measured data.

Table 3 shows the modelled results for the studied river basin of a country in Monsoon Asia. The data represent the average of daily calculations for 33 years (1976-2008).

Table 3 — Results for the calculated water footprint inventory

Items	Baseline (non-irrigated)		Rice paddy	
Unit	(m^3/ha)	(m^3/kg) (yield = 3.59 t/ha/ harvest)	(m^3/ha)	(m^3/kg) (yield = 5.39 t/ha/ harvest)
Rainfall (*R*)	8 880	2,48	8 880	1,65
Diverted water (Q_{divert}) [a]	0	0	14 900	2,76
Supplied water for irrigation [b]	0	0	(9 570)	(1,77)
Inflows from residual areas (Q_{res})	84 860 (surface) and 1 610 (groundwater)	23,6 (surface) and 0,45 (groundwater)	84 860 (surface) and 1 610 (groundwater)	15,7 (surface) and 0,30 (groundwater)
Returns into rivers (Q_{out})	92 060 (surface) and 320 (groundwater)	25,6 (surface) and 0,09 (groundwater)	102 680 (surface) and 370 (groundwater)	19,0 (surface) and 0,07 (groundwater)
Evapotranspiration (*ET*)	2 390	0,67	5 100	0,95
Seepage (I_{pad}) [c]	(5 530)	(1,54)	(6 230)	(1,16)
Storage change (ΔS)	580	0,16	2 100	0,38

All the values in this table were consistently normalized by the total area of grid cells covering the whole irrigation areas (127 km^2)

[a] The values of this row were calculated with the amount of diverted water from rivers.

[b] The values of this row were estimated with the supplied water for irrigation directly used for rice, so that they were included in those of diverted water (Q_{divert}).

[c] The values of seepage (I_{pad}) were included in those of the return flow into rivers (Q_{out}) plus storage change (ΔS).

The yield of rough rice in the region is 5,39 t/ha. Although the apparent withdrawal of water for irrigation is 9 570 m^3/ha (1 780 l/kg rough rice), the water evaporated is 5 100 m^3/ha (946 l/kg rough rice), or the water evaporated and that seeps is 11 330 m^3/ha (2 110 l/kg rough rice).

The baseline (chosen in this example being the natural system) implies a non-irrigation system with rainfed paddies. The production of rough rice is 3,59 t/ha in the area, assuming rainfed practices in Monsoon Asia. As the withdrawal of water for irrigation is zero, the water evaporated is 2 390 m^3/ha (668 l/kg rough rice), or the sum of the water that evaporates and that seeps is 7 920 m^3/ha (1 480 l/kg rough rice).

The difference between the baseline and the irrigated system gives the following results for water use: Due partly to the difference of yields between irrigated and baseline systems, the total water of both evapotranspiration and seepage (water consumption for rice) for an irrigation system decreases just by 100 l/kg rough rice to the baseline. This number indicates that irrigation in this example is quite an efficient water use activity.

The groundwater recharging of rice paddies in this particular example is 1 160 l/kg at basin level.

The major factor contributing to the water inventory, in this example, is irrigation water use.

This example shows the value of modelling at the basin scale rather than that at the field scale as the amount of water consumed by a crop is not necessarily the amount of water diverted for irrigation. This is where the consideration of a baseline in the modelling is important.

6.3 Example C – Water scarcity footprint of municipal water management

6.3.1 Goal and scope

This example illustrates how the water scarcity footprint of a system varies depending upon location, its application and use in options comparison.

A water utility is investigating the water scarcity footprints of three options (A, B and C) for the supply of 100 m^3 of water to a user in the industrial sector (therefore the functional unit is 100 m^3). The boundaries of the system are illustrated in Figure 5 showing where water is extracted from the environment, and returned to the environment.

The three options for supply of water are:

— A: Freshwater from Reservoir X in a region with high water scarcity + waste water discharged in the sea;

— B: Freshwater from Reservoir X + freshwater from Reservoir Y in a region with relatively low water scarcity;

— C: Freshwater from Reservoir X + recycling of treated waste water back to Reservoir X.

The elementary water flows are the freshwater inflows to the reservoir(s) (runoff and rainfall), evaporation losses and treated waste water discharged to the sea. For simplicity, other flows such as losses at the water treatment plant and in the distribution network are not considered. The water footprint inventory associated with background processes used in each of the three scenario is neglected, as it is the same in each case (assuming that reservoir X and Y are of the same size and structure, and distance to the user),

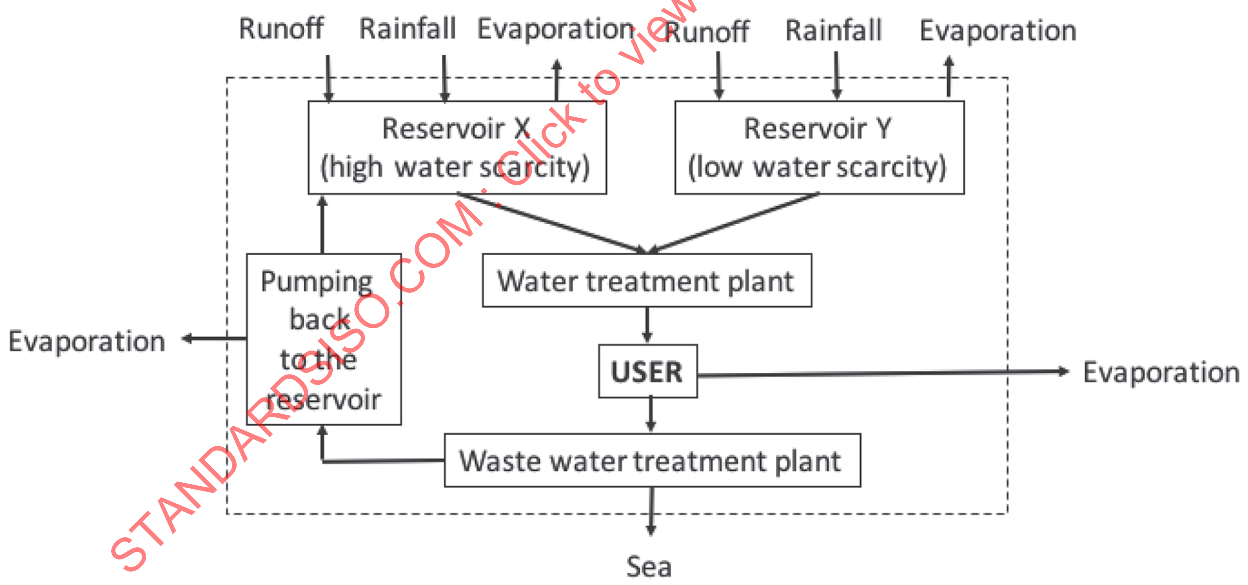


Figure 5 — Option for the supply of water to user

6.3.2 Inventory

The inventory is shown in Table 4. Losses incurred during pumping back to the reservoir are estimated at 9 %. A life cycle inventory using background databases shows that treating used water to the level that can be returned to user, including the associated infrastructure and energy, consumes 1 m^3 per 10 m^3 reused water.

Table 4 — Inventory of the different options (in m^3 per functional unit)

Line no.	Region	Option A [a]	Option B [a]		Option C [a]	
		X	X	Y	X	Z
1	Sum of runoff and rainfall inputs to the reservoir	111	71	40	71	—
2	Pumping back to the reservoir X (after losses from pumping back)	—	—	—	40	—
3	Evaporation from reservoir	11	7	4	11	—
4	Water input to water treatment plant	100	64	36	100	—
5	Water delivered to user	100	64	36	100	—
6	Water evaporated by user	30	19,2	10,8	30	—
7	Used water to waste water treatment plant	70	44,8	25,2	70	—
8	Treated waste water discharged to the sea	70	44,8	25,2	26	—
9	Losses during pumping back to reservoir X	—	—	—	4	—
10	Water consumed associated with the infrastructure used to allow the reuse (treating treated used water to the level that can be returned to user as well as the associated infrastructure and energy)	—	—	—	—	4

a This table uses fictive values which are not intended to be reproduced.

6.3.3 Impact assessment

The water scarcity footprint is calculated as the water consumed multiplied by the characterization factor for scarcity (being here, for example, the method of WULCA (Boulay et al. 2016)[5]) for each region where water consumption occurs (indicated in Figure 5).

The location Z where the water is consumed is unknown and is therefore assumed to be at the global average characterization factor for water scarcity (value of 20 for non-agricultural use type). The results of the impact assessment are shown in Table 5.

Table 5 — Water scarcity footprint results (per functional unit)

Region	Option A	Option B		Option C	
	X	X	Y	X	Z
Water consumption (m^3)	111	71	40	71	4
Characterization factor for the local water scarcity	80	80	4	80	20
Water scarcity footprint (m^3 H_2O-eq)	8 880	5 680	160	5 680	80
Water scarcity footprint (m^3 H_2O-eq)	8 880	5 840		5 760	

6.3.4 Interpretation

In this example, option C has the lowest water scarcity footprint, followed closely by option B. However, the differences between the water footprint results of alternative products, processes or organizations may not always be significant. In fact, in this example, when considering uncertainties associated with inventory values and especially the characterization factors for local water scarcity, it is fair to assume that options B and C have a similar water scarcity footprint but are both lower than option A.

NOTE It does not make a difference whether the water is evaporated by the user or discharged into the sea as in both cases it is not returned to the environment as freshwater. The impacts related to water scarcity occur at the place of water withdrawn and not where the water is evaporated or released into the sea.

6.4 Example D – Water scarcity footprint of rice cultivation (cradle-to-gate)

6.4.1 Goal and scope

This illustrative example describes the calculation of a water scarcity footprint, from cradle to farm gate of rice cultivated in a high water stress location, according to the method of Ridoutt and Pfister (2010)[6], using local characterization factors from Pfister et al. (2009)[7].

6.4.2 Inventory

In this example, the unit process "rice cultivation" involves elementary flows of rainfall (0,63 Ml/ha) and surface water used for irrigation (9,9 Ml/ha) during the cropping period (Figure 6). Other flows, determined by APSIM (Keating et al. 2003[26]) modelling, are evaporation from ponded water (3,2 Ml/ha), transpiration (6,4 Ml/ha) and drainage to saline coastal groundwater (0,93 Ml/ha). At the larger spatial scale, encompassing many individual rice fields, sideward flows between individual rice fields are disregarded. APSIM modelling is also used to determine that no deep drainage occurs under a scenario without rice cultivation and irrigation.

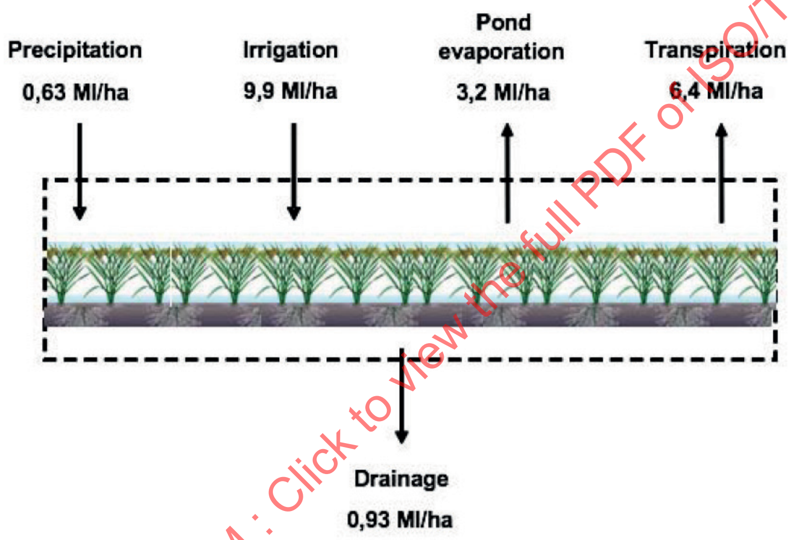


Figure 6 — Elementary flows of water in the rice cultivation example

Rice cultivation also uses a variety of material inputs (e.g. fuels, fertilizers and other agricultural chemicals). The water consumed to manufacture the material inputs used to cultivate 1 ha of rice field is estimated as 0,012 Ml based on best available data from a data provider. The location of water use for the production of these material inputs is unknown.

The production of rough rice is 8,7 t/ha at farm gate.

6.4.3 Impact assessment

The input of freshwater for irrigation is 9,9 Ml/ha (1 134 l/kg rough rice) at a location of high water scarcity (WSI of 1,00).

The rice cultivation system results in an increase of drainage (0,93 Ml/ha). However, this drainage is to saline coastal groundwater and is therefore no longer useable as freshwater.

The freshwater consumed in the manufacture of material inputs (0,012 Ml/ha or 1,4 l/kg rough rice) occurs at an unknown location. Therefore, the national average WSI (in this case 0,72) is applied.

To calculate the water scarcity footprint according to Ridoutt and Pfister (2010)[6], each instance of water consumed is multiplied by the relevant local WSI and divided by the global average WSI. These results are then summed across the product life cycle (from cradle to farm gate in this case; Table 6) and expressed in H_2O-eq.

Table 6 — Water scarcity footprint calculation

	Water consumed (l/kg)	Local WSI	WSF, considering local WSI	Global WSI	WSF considering normalization by global WSI
Irrigation	1 134	1,00	1 134	0,60	1 884
Material inputs	1,4	0,72	1	0,60	1,6
Total	—	—	1 135	—	1 885,6

The water scarcity footprint of rice in this particular example is 1 885 l H_2O-eq per kg at farm gate. What this means is that the production of 1 kg of this rice results in a burden on freshwater systems equivalent to 1 885 l of direct water consumption at the global average WSI.

The major factor contributing to the water scarcity footprint is irrigation. The water scarcity footprint of this rice is considered high because the irrigation occurs in a high water stress location (WSI of 1,00 on a scale from 0,01 to 1,00).

NOTE This example is not representative of rice production generally.

6.5 Example E – Water scarcity footprint of a textile with life cycle stages in different locations

6.5.1 Goal and scope

This example illustrates how assessment of environmental impacts related to water can lead to identification of different hotspots compared with the calculation of water quantities at the inventory level.

This example describes the calculation of the water scarcity footprint of a textile product - being the functional unit (FU) - where cotton production, manufacturing and use are in three different locations with different degrees of water scarcity.

The purpose of this example is to show the application of the concept of water scarcity footprint and show that different methods exist and lead to different results, something important to keep in mind when interpreting the results.

6.5.2 Inventory

The life cycle inventory results of this example as shown in Table 7.

Table 7 — Life cycle inventory for water consumption

Life cycle stage	Amount of water consumed per functional unit (L/FU)	Region where this water is consumed
Production	500	A
Manufacturing	100	B
Use (e.g. washing, drying over the product's lifetime)	1 000	C

6.5.3 Impact assessment

To calculate the water scarcity footprint, each instance of water consumed is multiplied by the relevant characterization factor for water scarcity, being the water scarcity index of the region where the water is consumed. These results are then summed across the product life cycle and expressed in the units specific to the characterization method used (Table 8).

Table 8 — Water scarcity footprint calculation

Life cycle stage	Water consumed (l/FU)	Location	Characterization factor considered (at the respective location A, B, and C) for the impact assessment method for water scarcity footprint by:							Water scarcity footprint using different impact assessment method (expressed in unit per functional unit)						
Impact assessment method [a]	—	—	M1	M2	M3	M4	M5	M6	M7	M1	M2	M3	M4	M5	M6	M7
Expressed in [b]	—	—	m^3-eq /m^3	m^3-eq /m^3	UBP /m^3	m^3-eq /m^3	m^3-eq /m^3	m^3-eq /m^3	m^3-eq /m^3	m^3-eq /FU	m^3-eq /FU	UBP /FU	m^3-eq /FU	m^3-eq /FU	m^3-eq /FU	m^3-eq /FU
Production	500	A	100	1,00	8,00	1,00	1,00	4,00	1,00	50 000	500	4 000	500	500	2 000	500
Manufacturing	100	B	1	0,60	0,04	0,17	0,70	1,00	0,50	100	60	4	17	70	100	50
Use	1 000	C	20	0,80	4,00	0,50	0,50	2,00	0,70	20 000	800	4 000	500	500	2 000	700
Water scarcity footprint	—	—	—	—	—	—	—	—	—	70 100	1 360	8 004	1 017	1 070	4 100	1 250

a Impact assessment method used.

— M1: Boulay et al. (2016) (WULCA)[5]

— M2: Pfister et al. (2009)[7]

— M3: Frischknecht et al. (2008)[8]

— M4: EU (2013) (PEF/OEF)[9]

— M5: Boulay et al. (2011a)[10]

— M6: Hoekstra et al. (2012) (Water Footprint Network - WFN)[11]

— M7: Berger et al. (2014)[12]

b Though different impact assessment methods may use "m^3-eq" as a unit (short for "m^3 H_2O-eq"), those "m^3-eq" may not refer to the same equivalence.

6.5.4 Interpretation

For example, considering the approach of WULCA (Boulay et al. 2016)[5], the water scarcity footprint is 70 100 l H_2O-eq per functional unit.

Some methods suggest expressing the results in relation to, for example, the global average water scarcity (used as a reference), while some methods (i.e. WULCA) include such reference flow inside the characterization factor, eliminating therefore the step of division by the global average water scarcity.

In this example, one observes that the use stage is the life cycle stage with the highest water consumption. However, the impact assessment shows that cotton production and consumption can have a comparable water scarcity footprint, or, in some case, even different rankings. Hence the choice of method and the range of its values (e.g. "0,01 to 1" as opposed to "0,1 to 100") can influence the resulting life cycle stages contribution. Careful interpretation of the results and meaning of the indicator according to the method chosen is therefore very important.

This example also shows that it is important to consider the impact assessment step as the relative contribution of two life cycle stages can be reversed at the impact level as compared to the inventory level.

6.6 Example F – Water scarcity footprint of reservoir operation, reflecting seasonality

6.6.1 Goal and scope

This example illustrates the role of seasonality in assessing water scarcity.

The goal of the study is to determine the direct water scarcity footprint of a reservoir, taking into account seasonality of flows and of water scarcity.

The function of the reservoir is to supply water in controlled quantities for generation of hydropower, irrigation and municipal water supply. This includes retaining water from the wet season (November – March) to be used in the dry season (April – October).

The reporting unit is one year of activity of the reservoir.

6.6.2 Inventory

The reservoir covers a surface area of 20 km^2, in a semi-arid region. Average annual evaporation and annual transpiration from local vegetation prior to the construction of the dam is equal to annual average precipitation (500 mm/a, i.e. 10 Mm^3 for 20 km^2). However, following construction of the dam, evaporation from the reservoir surface increases to 1 500 mm/a, i.e. 30 Mm^3 for 20 km^2. This means that the total additional annual water loss related to the construction of the dam is 20 Mm^3/a.

The reservoir has a constant outflow rate throughout the year. The water inflow, before and after the construction of the dam is identical. The local annual characterization factor for water scarcity is 0,38.

Table 9 shows the annual variation in the water balance of the 20 km^2 area before (baseline) and after (with reservoir).

Table 9 — Annual variation in the water balance of a reservoir (in Mm^3/a)

	Baseline	With reservoir	Reduction in outflow
Inflow (from the catchment area)	630,7	630,7	—
Precipitation (over the area covered by the reservoir)	10,0	10,0	—
Evaporation (over the area covered by the reservoir)	10,0	30,0	—
Outflow (downstream of the reservoir location)	630,7	610,7	20,0

The seasonality is reflected by determining the water inputs and the water outputs on a monthly basis (Table 10). The monthly water balance of the dam is calculated as the difference between water inflow to the reservoir and the water outflow from the reservoir.

The water volume in the reservoir is reduced from the maximum value of 312 Mm^3 at the end of the rainy season to a minimum value of 117 Mm^3 at the end of the dry season.

6.6.3 Impact assessment

When the seasonality and the positive effect of the reservoir on water scarcity are taken into account, then the fact that water is retained in the reservoir during the wet season and released for irrigation and municipal water supply during the dry season needs to be considered, taking into account the data as presented in Table 10. For this purpose, the characterization factors assessing water scarcity and the water scarcity footprint are determined on a monthly basis, by multiplying the monthly water balances by the monthly characterization factors according to Pfister and Bayer (2014).[13] The annual water scarcity footprint is the sum of the monthly values.

Table 10 — Inventory and impact assessment

Reporting month	Water inflow Mm³/month	Evaporation Mm³/month	Precipitation Mm³/month	Water outflow Mm³/month	Water volume in reservoir Mm³/month	Monthly water balance Mm³/month	Monthly characterization factor CFSc,L,n / CFSc,Glo	Water scarcity footprint Mm³ H_2O-eq/month
January	100,0	0,2	1,0	50,9	249,9	49,1	0,05	2,5
February	100,0	0,2	2,0	50,9	300,8	49,1	0,05	2,5
March	60,0	0,5	2,3	50,9	311,8	9,1	0,2	1,8
April	40,0	1,5	2,0	50,9	301,4	−10,9	0,3	−3,3
May	45,7	3,0	1,3	50,9	294,5	−5,2	0,4	−2,1
June	10,0	6,0	0,3	50,9	248,0	−40,9	0,7	−28,6
July	10,0	7,0	0,1	50,9	200,2	−40,9	0,9	−36,8
August	10,0	6,0	0,1	50,9	153,4	−40,9	0,9	−36,8
September	20,0	4,0	0,1	50,9	118,5	−30,9	0,7	−21,6
October	50,0	1,0	0,1	50,9	116,7	−0,9	0,2	−0,2
November	85,0	0,3	0,2	50,9	150,7	34,1	0,1	3,4
December	100,0	0,3	0,5	50,9	200,0	49,1	0,05	2,5
Total	—	—	—	—	—	20,0	—	−117

6.6.4 Interpretation

In Table 10, a monthly water scarcity footprint is calculated which results in positive figures in the wet season where more water is collected in the reservoir than released, and negative figures in the dry season where more water is released than collected.

Because of the different water scarcity indexes, the sum of the monthly water scarcity footprints is a negative figure, i.e. −117 Mm³ H_2O-eq/a.

This example shows the importance of seasonality. Without consideration of seasonality, the water scarcity footprint would have been simply the increased amount of water evaporated (20 Mm³/a), multiplied by the local annual average characterization factor (being 0,63 in this example), resulting in a water scarcity footprint of 13 Mm³ H_2O-eq/a. This would imply that the reservoir has increased downstream water scarcity. However, by considering the seasonality, the water scarcity is negative (-117 Mm³ H_2O-eq/a), illustrating that the positive effect of increased water available for irrigation and municipal water supply in the dry season is higher than the negative effect due to evaporation and reduced flow during wet season. In this example, by retaining water in the wet season, the reservoir has reduced downstream water scarcity.

A reservoir typically has other environmental impacts than increasing or decreasing water scarcity (such as global warming emissions from organic matter degradation when the reservoir is created, degradation of fisheries, sedimentation and erosion arising from the construction of reservoirs and changes in the hydrological regime, impacts on biodiversity and degradation of the water quality). In order to address such additional impacts, a comprehensive set of impact categories in addition to water scarcity, needs to be worked out.

6.7 Example G – Water scarcity footprint and water availability footprint of packaging production

6.7.1 Goal and scope

This example illustrates calculation of a water availability footprint as distinct from a water scarcity footprint (see ISO 14046:2014, 5.4.5).

The production of a packaging material is used as a case study.

The example only accounts for direct water use and emissions at the factory and not for indirect water use and emissions associated with input materials or energy or treatment of waste exported from the factory.

6.7.2 Inventory

The water input, water output and emissions to water for 1 t of a specific packaging material in an area X is shown in Table 11. The chemical composition of the incoming water is unknown, but in this region, available water is assumed to be suitable for standard potable water supply.

Table 11 — Collected inventory data for 1 t of a specific packaging material production (only site specific inventory, not showing the supply chain)

		Input or output	**Concentration in output water** mg/l
Surface water input		38 m^3	—
Surface water output		37 m^3	—
Quality parameters of output water	BOD (5 days)	3,4 kg	93
	COD	12 kg	329
	TOC	1,9 kg	52
	Nitrogen (in compounds)	0,2 kg	5,5
	Phosphorus (in compounds)	0,038 kg	1,04
	Suspended solids, unspecified	2,3 kg	63

6.7.3 Impact assessment

Two different types of water footprint results are calculated in order to illustrate the application of various aspects of the standard.

a) Water scarcity footprint: The purpose of a water scarcity footprint is to assess the contribution of the product, process or organization to water scarcity. Water scarcity considers only water quantity and not how degradation affects its availability to users (see ISO 14046).

b) Water availability footprint: This result represents impacts from lower water availability due to water consumption and degradation.

6.7.3.1 Water scarcity footprint

For this assessment, the method provided in Boulay et al. (2011a)[10] is used in the simplified version provided online (http://www.ciraig.org/fr/wateruseimpacts.php). This method provides scarcity indicators (named water stress index α in this reference), based on consumption-to-availability ratio.

They cover the entire globe and can be obtained using satellite imagery, for both surface and ground resources. When the input resource is unknown, the “unspecified” data can be used as it is a weighted average of surface and groundwater indicators based on the withdrawal fraction of each resource. The parameters can be used to calculate the scarcity footprint with Formula (1):

$$F_{\mathrm{WS}} = V_{\mathrm{in}} \times \alpha_{\mathrm{WS,in}} - V_{\mathrm{out}} \times \alpha_{\mathrm{WS,out}} \quad (1)$$

where

F_{WS} is the water scarcity footprint;

V_{in} is the volume of water which enters the system;

$\alpha_{WS,in}$ is the water scarcity index at the location where the water enters the system;

V_{out} is the volume of water which leaves the system;

$\alpha_{WS,out}$ is the water scarcity index at the location where the water leaves the system.

In this example, 38 m^3 of water is withdrawn from a river (surface water) and the 37 m^3 is discharged to the same river. The water scarcity index for surface water in region X is 0,45 m^3 H_2O-eq/m^3 consumed. Since 1 m^3 of water is consumed, and there is no change of water source, the water scarcity footprint (only associated with the site water use and emissions) to produce 1 t of that specific packaging material is 1 m^3 consumed x 0,45 m^3 H_2O-eq/m^3 consumed = 0,45 m^3 H_2O-eq.

6.7.3.2 Water availability footprint

The water availability footprint allows an evaluation of how other water users would potentially be deprived from these resources if they are consumed or degraded to a point beyond functionality.

Similar to the indicator results of other impact categories, the water availability footprint of a unit process is calculated with Formula (2):

$$F_{WA} = \sum_i \left(V_i \times \alpha_{av,i} \right) \quad (2)$$

where

F_{WA} is the water availability footprint;

V_i is the volume of the water input (positive) or water output (negative);

$\alpha_{av,i}$ is the characterization factor for each V_i, which can be obtained for each water category (i) from http://www.ciraig.org/fr/wateruseimpacts.php.

The characterization factor $\alpha_{av,i}$ is a quality-adjusted index, which is based on the ratio between net water consumption and water availability (Boulay et al. 2011a[10]). It is specific for each water category (Boulay et al. 2011b[32]), ranges from 0 to 1, and is regionalized by drainage basin or country

For the water availability footprint, the quality of water inputs and water outputs is considered by defining water categories. For each water category, the local water stress is based on the water availability and the water consumption within the relevant region. This approach is based on the definition of the water categories presented in (Boulay et al. 2011b[27]) and shown in Table 12.

Table 12 — Qualitative definition of water categories

Excellent	Good	Average	Average-tox	Average-bio	Poor	Very poor	Unusable
1	2a	2b	2c	2d	3	4	5
low coli-forms, low toxic	low coli-form, medi-um toxic	medium coliform, medium toxic	low coliform, higher toxic	high coli-forms, low toxic	high coli-form, medi-um toxic	high coli-form, high toxic	other - unus-able
NOTE For quantitative values of contaminants for each category, refer to Boulay et al. (2011b)[27].							

For the application of this method, assessing the water category of the input and output flows is necessary for the calculation of the water availability footprint. This can be performed based on available data in different ways, from the less data-intensive alternative to the most.

a) Default and qualitative assessment: based on geographical location, default input water quality category can be obtained from Boulay et al. (2011b)[27]. Output water quality category can be based on the qualitative assessment presented in Table 12.

b) Default and generic assessment: based on geographical location, default input water quality can be obtained from Boulay et al. (2011b)[27]. Output water quality category can be assessed using reported industry effluent values and the water category calculator available here: http://www.ciraig.org/fr/wateruseimpacts.php.

c) Specific assessment: primary data can be used for input and/or output water quality and the relevant category assessed using the water category calculator.

In the present example the elementary flows are described by

— the volume of the water input and water output;

— the type (groundwater or surface water) and geographical location of the water body from which the input water is withdrawn or to which the output water is released (here to surface);

— the quality of the input water is not known but as per definition in Boulay et al. (2011b)[27] and knowing that the local water can be made potable by a standard treatment, the input water quality is set to 2a. Alternatively, this can be verified using the default water qualities of water available world-wide as published in Boulay et al. (2011b)[27];

— the output water quality is assessed using specific effluent data (see Table 11) and using the water category definition Boulay et al. (2011b)[27] or water category calculator available as an online tool[28]. It is assessed to be of category 5, as described in Boulay et al. (2011b)[27], not directly usable for irrigation or potable water production without additional treatment or dilution.

More detailed criteria for the distinction of the different water categories, based on their biological and chemical composition, are described in Boulay et al. (2011b)[27].

It is considered that the less functional a water category is, the more abundant it will be, since all higher quality categories will also meet the functionality requirements of this category. This is a consequence of water categories being defined by upper thresholds of a contaminant concentration instead of ranges, as they are functionality-based. For example, water of category 3 would also include water of category 2 and 1, and so on.

In the present example, the characterization factor $\alpha_{av,2a}$ for the water category 2a in the relevant region is 0,86, and for category 5 the characterization factor $\alpha_{av,5}$ is 0 (meaning that no user is deprived when category 5 is consumed).

The resulting water availability footprint (only associated with the site water use and emissions) is 32,5 m^3 H_2O-eq (being 0,86 × 38 m^3 – 0 × 37 m^3).

When the indicator of water availability footprint, as presented in this example, is used in a comprehensive water footprint, it should be understood that there may be double counting of impacts on human health, as either toxicity impacts or (un)availability impacts may occur. Alternatively, the water scarcity footprint can be used instead of the water availability footprint in a complete profile.

6.8 Example H – Water scarcity footprint differentiated by source of water

6.8.1 Goal and scope

This example illustrates the assessment of different types of water resources.

The potential impacts associated with water use can vary between different types of water resource (e.g. surface water, groundwater). In this example, the water scarcity footprint is calculated for use of the same quantity of water in a wheat cultivation system at two different locations (A and B) which each use different proportions of surface and groundwater.

Water use for fertilizers, pesticides, and machines production are not included in this illustrative example and allocation procedures are not considered.

6.8.2 Inventory

In this example, river water and water from medium-size reservoirs are considered as surface water, and water in aquifers as groundwater.[34] The volumes of evapotranspiration from the supplementary irrigation from both surface water and groundwater applied during the cropping periods (Table 13) are calculated for the water footprint inventory using the method of Hanasaki et al. (2010)[29].

6.8.3 Impact assessment

The characterization factors at locations A and B are determined using the method described in Yano et al. (2015)[14], and are shown in Table 13.

The water scarcity footprint (F_{WS}) is calculated with Formula (3).

$$F_{WS} = V_{Sw} \times \alpha_{SC,Sw} + V_{Gw} \times \alpha_{SC,Gw} \tag{3}$$

where

V_{Sw} is the volume of evapotranspiration from surface water irrigation, in m^3;

$\alpha_{SC,Sw}$ is the local characterization factor for surface water;

V_{Gw} is the volume of evapotranspiration from groundwater irrigation, in m^3;

$\alpha_{SC,Gw}$ is the local characterization factor for groundwater.

Table 13 shows the results for the water scarcity footprint of 1 t wheat for two farms in the same drainage basin but with different fraction of water source. The total quantity of water used is the same in both cases, and the characterization factors for surface and groundwater are the same in both cases. However, farm A uses more groundwater and farm B uses more surface water. As a result, the water scarcity footprint of wheat produced in farm A is higher than in farm B.

Table 13 — Example of life cycle impact assessment for wheat production for farm A and B

	Water source	Yield of wheat (t/ha)	Water footprint inventory of wheat (m^3/t)	Local characterization factor	Water scarcity footprint of wheat (m^3 H_2O-eq/t)
Farm A	Surface water	—	10	3,0	30
	Groundwater	—	140	3,8	530
	Total	7,12	—	—	560
Farm B	Surface water	—	140	3,0	420
	Groundwater	—	10	3,8	40
	Total	7,12	—	—	460

6.8.4 Interpretation

In this example, the characterization factor for surface water is smaller than that for groundwater, meaning that there is more surface water available as compared to groundwater. Because of the small difference between the two characterization factors, the water scarcity footprint is more influenced by the relative quantities of surface and groundwater used in wheat production.

NOTE H_2O-eq in this example reflects the availability of each water source in a location which is normalized against 1 000 mm/a.

6.9 Example I – Variation of water scarcity by forest management and land use

6.9.1 Goal and scope

This example illustrates how different types of land use affect the characterization factors for water scarcity footprints.

The functional unit is 1 l beer, and barley/hop cultivation and subsequent beer production takes place in three different locations: a forested drainage basin without thinning, a forested drainage basin with thinning, and an urban drainage basin.

To simplify, it is assumed that production of the ingredients and the beer production occur within the same drainage basin.

6.9.2 Inventory

The water footprint inventory is shown in Table 14 and is the quantity of water consumed for human activities, i.e. production of ingredients, brewing and bottling, and waste disposal[30][31]. It is assumed that the irrigation uses only surface water and that brewing and bottling processes use only groundwater.

Table 14 — Water footprint inventory of 1 l of beer production

Water source	Water footprint inventory (litres of water per litre of beer)		
	Ingredients	Brewing and bottling	Waste disposal
Surface water	17,9	0	0
Groundwater	0	4,3	0

6.9.3 Impact assessment

The water footprint impact assessment is conducted using a drainage basin based approach.

In this example, the method of Yano et al. (2015)[14] is used to calculate the characterization factors for each water resource type in each location, and reflect the hydrological conditions (based on data in Ando et al. (1984)[32] and Kubota et al. (2013)[33]). The characterization factors for different water resource types consider water availability reflecting different forest management and land use in each location.

The water scarcity footprint is calculated from the water footprint inventories in Table 14 and the local characterization factors, by summing up the characterized results for each of the water resource types, as shown in Table 15.

Table 15 — Results of the water scarcity footprint of beer production in each land surface condition

Drainage basin	Water source	Local characterization factor (m^2/m^2)	Water scarcity footprint of beer ($l\ H_2O$-eq / l)			
			Ingredients	Brewing and bottling	Waste disposal	Total
Forested drainage basin without thinning	Surface water	1,7	30,4	0	0	39,0
	Groundwater	2,0	0	8,6	0	
Forested drainage basin with thinning	Surface water	1,5	26,9	0	0	34,6
	Groundwater	1,8	0	7,7	0	
Urban drainage basin	Surface water	1,4	25,1	0	0	50,4
	Groundwater	5,9	0	25,4	0	

6.9.4 Interpretation

The results show that, even though the water footprint inventory data are identical, the water scarcity footprints are different because the characterization factors are influenced by the hydrological conditions that depend on the types of land use management. Indeed, the type of land use management influences components such as surface water runoff and groundwater recharge rates.

NOTE H_2O-eq in this example reflects the availability of each water source in a location which is normalized against 1 000 mm/a.

6.10 Example J - Water eutrophication footprint of maize cultivation, calculated as one or two indicator results

6.10.1 Goal and scope

This example illustrates that an area of concern (e.g. water eutrophication) can be represented as one impact indicator result or several impact indicator results.

The example chosen is the assessment of the water eutrophication footprint of maize production in a region X.

6.10.2 Inventory

Table 16 summarizes elementary flows contributing to water eutrophication assessed through a life cycle inventory analysis using both collected data and data gathered using background databases.

Table 16 — Elementary flows contributing to water eutrophication

Substance	Compartment of emission	Amount emitted, in kg per t of maize [a]		
		Upstream (e.g. from input materials)	Direct emissions (e.g. during cultivation)	Total
Ammonia	Air	0,084	1,096	1,180
Nitrogen oxides	Air	0,718	0,298	1,016
COD	Water	0,610	0,000	0,610
Nitrate	Water	3,107	23,909	27,016
Phosphorus	Water	0,002	0,105	0,107

[a] This table uses fictive values which are not intended to be reproduced.

6.10.3 Impact assessment

Two methods are selected to assess water eutrophication:

— the PEF/OEF method of the EU (2013)[9], which assesses impacts from eutrophication for P-limited and N-limited drainage basins separately, is used as a first method;

— a sensitivity analysis is performed with method IMPACT 2002+ (Jolliet et al. 2003)[15] that assesses impacts from water eutrophication considering both P-based and N-based substances in a single impact category.

The characterization factors for calculating water eutrophication potential from those two methods are presented in Table 17.

Table 17 — Characterization factors for water eutrophication for the two impact assessment methods chosen

Substance (and compartment of emission)	Water eutrophication potential		
	Impact assessment method PEF/OEF (EU 2013[9])		Impact assessment method IMPACT 2002+ (Jolliet et al. 2003[15])
	P-limited drainage basins (expressed in kg P-eq per kg of maize)	N-limited drainage basins (expressed in kg N-eq per kg of maize)	Undefined drainage basins (expressed in kg PO_4^{3-}-eq per kg of maize)
Ammonia, to air	0	0,092	0,175
Nitrogen oxides, to air	0	Not provided (characterization factor of Nitrogen dioxides, to air, of 0,389 is used as a proxy)	0,065
COD, to water	Not provided	Not provided	0,022
Nitrate, to water	0	0,226	0,05
Phosphorus, to water	1	0	1,53

Table 18 presents the calculation of the water eutrophication footprint. It is simply the amount of substance emitted into the environment multiplied by its respective characterization factor.

Table 18 — Calculation of the water eutrophication footprint for both impact assessment methods

Substance (and compartment of emission)	Amount emitted (kg per t of maize)	Water eutrophication potential		
		Impact assessment method PEF/OEF (EU 2013[9])		Impact assessment method IMPACT 2002+ (Jolliet et al. 2003[15])
		P-limited drainage basins (expressed in kg P-eq per kg of maize)	N-limited drainage basins (expressed in kg N-eq per kg of maize)	Undefined drainage basins (expressed in kg PO_4^{3-}-eq per kg of maize)
Ammonia, to air	1,180	0	0,109	0,207
Nitrogen oxides, to air	1,016	0	0,395	0,066
COD, to water	0,610	n/a	n/a	0,013
Nitrate, to water	27,016	0	6,106	1,351
Phosphorus, to water	0,107	0,107	0	0,164
Total	—	0,107	6,609	1,800

As the final result, the water eutrophication footprint, expressed in kg of a reference substance equivalent (a typical midpoint unit), caused by the production of 1 t of maize is assessed to be:

— 0,107 kg P-eq and 6,609 kg N-eq for P-limited drainage basins and N-limited drainage basins respectively, by the impact assessment method PEF/OEF;

— 1,800 kg PO_4^{3-}-eq by the impact assessment method IMPACT 2002+.

6.10.3.1 Interpretation

This example shows that emissions emitted to compartments other than water (in this case to air) can also contribute to water degradation footprint.

This example also shows that different impact assessment methods assess an impact differently: in this case the PEF/OEF method assesses water eutrophication footprint as a profile of two impact indicator results whereas the IMPACT 2002+ method assesses water eutrophication as a single indicator result.

This example also shows that different impact assessment methods can have a different coverage of substances. For example, in this example the PEF/OEF impact assessment method does not provide characterization factors for COD. This can be either due to the fact that this impact assessment method explicitly considered COD as not being a cause of water eutrophication or because the characterization factor is simply missing. This shows the importance to understand if some substances are not characterized by a method and if so why. If a characterization factor is missing, it may be wise to either add this missing characterization factor, change impact assessment method or at least reflect it in the interpretation and limitations of the study.

NOTE 1 A characterization factor of 0 is not the same as a missing characterization factor: a characterization factor of 0 is an explicit statement that this substance is not considered to contribute to this impact category, whereas a missing characterization factor does not give any information on why this substance is not characterized in that specific impact assessment method.

This example also shows that different units can be used to express the results of the same impact. In this example, three different units – “kg P-eq”, “kg N-eq” and “kg PO_4^{3-}-eq” – are used to express water eutrophication potential.

NOTE 2 The approach using the P-limited and N-limited impact categories for water eutrophication is based on the assumption that the impacts are linked to only the dominant pollutant: however, in that case both impact categories are presented together to provide a complete picture of the water eutrophication issue.

6.11 Example K – Comprehensive water footprint profile of packaging production

6.11.1 Goal and scope

This example illustrates the reporting of a comprehensive water footprint at midpoint and endpoint levels. It provides an example of different impact categories that can be found in a comprehensive profile.

According to ISO 14046, this option can be referred to as a "water footprint".

This example is a cradle-to-gate example of 1 t of a specific fibre-based packaging material in a specific location.

6.11.2 Inventory

The water footprint inventory comprises both the foreground and background water footprint inventories. The foreground water footprint inventory is based on primary data collected at the production site for direct water withdrawal and release, direct emissions to air, soil and water as well as direct activity data of the site (e.g. amount of electricity consumed, amount of fuel consumed, amount of material input) per t of packaging material produced. The background water footprint inventory (i.e. the water footprint inventory associated with electricity, energy and material purchased by the factory as well as for the treatment of waste exported from the factory) is calculated using an inventory database where the inventory data have been determined and processed according to ISO 14046.

The water footprint inventory data are derived from an inventory database (Ecoinvent 2015[34]).

6.11.3 Impact assessment

With a comprehensive assessment expressed as a water footprint profile, using existing models, all water-related impacts can be captured. This can be done by one of the following:

— manually, by calculating each of the indicator results below (or by justifying the ones to leave out);

— using LCA tools, which integrate available methods, and can be used within available software and using current databases.

For the purpose of this example, the data set obtained in the water footprint inventory analysis is characterized for each impact category and the respective characterization models presented in Table 19.

The resulting indicators are shown in Table 19 or in Table 20. All three presentations can be referred to as water footprint.

Table 19 — Water footprint profile expressed at the level of impact categories, expressed at the level of midpoint and endpoint respectively (for 1 t of a specific packaging material)

Type of impact	Impact category	Assessment at midpoint			Assessment at endpoint		
		Impact indicator results	Units	Method	Impact indicator results	Units	Method
Water degradation footprint	Freshwater ecotoxicity	14 300	CTU_e	USEtox (Rosenbaum et al. 2008[17])	7,8	PDF.m^2.a	Using $5,48 \times 10^{-4}$ PDF.m^2.a / CTU_e
Water degradation footprint	Marine ecotoxicity	$2,11 \times 10^6$	kg 1,4-DB-eq	CML baseline v3.02 (Guinée et al. 2001[18])	$5,17 \times 10^6$	PDF.m^2.a	Using freshwater ecotoxicity of 1,4-DB of IMPACT 2002+ (Jolliet et al. 2003[15]) as a proxy (2,45 PDF.m^2.a / kg 1,4-DB) [a]
Water degradation footprint	Freshwater acidification	12	mol H^+-eq	PEF/OEF (EU 2013[9])	0,08	PDF.m^2.a	Using $6,73 \times 10^{-3}$ PDF.m^2.a/mol H^+ e
Water degradation footprint	Marine acidification	1 700	kg CO_2	Only CO_2 emissions are considered in this impact category	284	PDF.m^2.a	IMPACT World+ (Bulle et al. 2016[16])
Water degradation footprint	Freshwater eutrophication	0,876	kg P-eq	PEF/OEF (EU 2013[9])	14,6	PDF.m^2.a	IMPACT World+ (Bulle et al. 2016[16])
Water degradation footprint	Marine eutrophication	1,98	kg N-eq	PEF/OEF (EU 2013[9])	3,01	PDF.m^2.a	IMPACT World+ (Bulle et al. 2016[16])
Water degradation footprint	Ionizing radiation (impact on freshwater ecosystem)	0,001 1	CTU_e	USEtox (Rosenbaum et al. 2008[17])	6×10^{-7}	PDF.m^2.a	Using $5,48 \times 10^{-4}$ PDF.m^2.a/CTU_e
Water degradation footprint	Ionizing radiation (impact on marine water ecosystem)	n/a	CTU_e	n/a	n/a	PDF.m^2.a	n/a
Water degradation footprint	Thermally polluted water	0,001 98	PDF.m^2.a	Verones et al. 2011[19]	0,001 98	PDF.m^2.a	Verones et al. 2011[19] as implemented in IMPACT World+
Water degradation footprint	Human toxicity carcinogens	$9,49 \times 10^{-5}$	$CTU_{h,c}$	USEtox (Rosenbaum et al. 2008[17]), as modified in[16]	0,001 2	DALY	USEtox, converted to DALY considering 13 DALY/$case_c$ (Humbert et al. 2015[35])
Water degradation footprint	Human toxicity Non-carcinogens	0,000 89	$CTU_{h,n-c}$	USEtox (Rosenbaum et al. 2008[17]), as modified in[16]	0,001 2	DALY	USEtox, converted to DALY considering 1.3 DALY/$case_{n-c}$ (Humbert et al. 2015[35])

[a] To be taken with care

Table 19 *(continued)*

Type of impact	Impact category	Assessment at midpoint			Assessment at endpoint		
		Impact indicator results	Units	Method	Impact indicator results	Units	Method
Water degradation footprint	Ionizing radiation (impact on human health)	588	kBq U235-eq	PEF/OEF (EU 2013[9])	$1{,}23 \times 10^{-5}$	DALY	IMPACT World+ (Bulle et al. 2016[16])
Water scarcity footprint	Impacts associated with water consumption	10	m^3 H_2O-eq	WULCA (Boulay et al. 2016[5])	$4{,}6 \times 10^{-3}$	DALY	Boulay et al. 2011a[10] as implemented in IMPACT World+
					0,001	PDF.m^2.a	Hannafiah et al. 2011[20] as implemented in IMPACT World+

a To be taken with care

Expressing the results in endpoint units indicates which impact category is contributing more to the impact on each area of protection.

If deemed necessary, the water footprint profile can be expressed grouping all impact categories contributing to impact on the area of protection human health and those contributing to impact on the area of protection ecosystem (as shown in Table 20).

Table 20 — Water footprint profile expressed at the level of area of protection (and using endpoint units)

Type of impact	Area of protection	Impact indicator results	Units	Method
Water degradation footprint	Ecosystems	310 (up to 5×10^6 if Marine water ecotoxicity is considered a)	PDF.m^2.a	Sum of Freshwater ecotoxicity, Freshwater acidification, Marine acidification, Freshwater eutrophication, Marine eutrophication, Ionizing radiation (impact on freshwater ecosystems), Thermally polluted water, as well as Marine water ecotoxicity if considered robust. Marine water impact from ionizing radiation is missing from the list due to lack of data.
Water degradation footprint	Human health	0,024	DALY	Sum of Human toxicity (carcinogens), Human toxicity (non-carcinogens) and Impact on human health from Ionizing radiation
Water scarcity footprint	Human health	$4{,}6 \times 10^{-3}$	DALY	Water deprivation for human users
Water scarcity footprint	Ecosystems	0,001	PDF.m^2.a	Water use impacts on ecosystem

a To be considered with care as the method of CML may be overestimated for marine ecotox and the conversion factor is based on freshwater ecotox. More research is needed in this area as marine ecotox may be the dominant issue for water degradation footprint.

NOTE Following the scope of ISO 14046, whatever the approach used (i.e. midpoint or endpoint), the impact categories related to human toxicity (cancer, non-cancer, and from ionizing radiations) within the water degradation footprint only account for emissions reaching humans through either water emission or through air and soil emissions going to water and reaching humans, e.g. through water consumption, seafood consumption. In practice, impact assessment models might not always be able to do so. For example, in the default version of the USEtox model (Rosenbaum et al. 2008[17]) impacts on human health (from those three impact categories) associated with every fate and exposure pathway is accounted for and is therefore an overestimation of the impacts on human health from water degradation footprint. The model and method IMPACT World+ (Bulle et al. 2016[16]) allows to take into account the fate of the contaminant in water, and hence only the relevant fraction to the water footprint.

6.11.4 Interpretation

Research is on-going to address other aspects related to water ecosystems than those listed in Table 19 and Table 20 above, such as groundwater table reduction (e.g. as Van Zelm et al. 2011[36]) or water stream management (related to, for example, dams) (e.g. Humbert and Maendly 2009[37]). Practitioners are recommended to integrate state of the art practices.

6.12 Example L – Non-comprehensive weighted water footprint of cereal cultivation

6.12.1 Goal and scope

This example illustrates calculation of a water footprint profile and subsequent weighting into a single stand-alone indicator.

This example describes the calculation of a water footprint according to the method of Ridoutt and Pfister (2013)[22] which integrates consumptive and degradative water use (respectively CWU and DWU) into a single stand-alone indicator. The method uses weighting, is based on the ReCiPe impact assessment methodology (Goedkoop et al. 2009[21]), and utilizes the local characterization factors for freshwater consumption reported by Pfister et al. (2009)[7].

Water consumed and emissions affecting water quality in the production, supply and application of fertilizer, as well as other farming operations (e.g. cultivating, harvesting) are excluded in this simplified example.

NOTE Because this method uses weighting, the results cannot be used if the water footprint study is part of an LCA study used in comparative assertions intended to be disclosed to the public (see ISO 14044:2006, 4.4.5).

6.12.2 Inventory

The example is of a cereal cropping system involving 2 000 m^3 per ha of freshwater consumed for irrigation (local water scarcity index 0,20), and emissions of 4 kg phosphate per ha to freshwater. The crop yield is 4,5 t per ha.

6.12.3 Impact assessment

Following Ridoutt and Pfister (2013)[22], the indicator results for water scarcity footprint (F_{WS}) and water degradation footprint (F_D) are calculated according to Formulae (4) and (5), and expressed in the reference units H_2O-eq, where 1 m^3 H_2O-eq represents the burden on water systems from 1 m^3 of freshwater consumption at the global average water scarcity index (Ridoutt and Pfister 2010)[6].

$$F_{\text{WS}} = \Sigma_i \left(V_{\text{c},i} \times \frac{\alpha_i}{m} \right) \tag{4}$$

where

F_{WS} is the water scarcity footprint in H_2O-eq per unit of production;

M is the mass of production;

$V_{C,i}$ is the water consumed by production at location i;

α_i is the relevant local water scarcity characterization factor for location i;

and

$$F_{\text{D}} = \frac{R_{\text{EWPS}}}{m \times R_{\text{x}}} \tag{5}$$

where

F_D is the water degradation footprint expressed in m^3 H_2O-eq per unit of production;

R_{EWPS} is the ReCiPe points determined for emissions to water for the production system;

R_x is the global average ReCiPe points F_D attributable to 1 m^3 of H_2O-eq (1,86 × 10^{-3} ReCiPe points per m^3);

m is the mass of production.

The single value, stand-alone water footprint result is obtained by summing the indicator results for water scarcity footprint and water degradation footprint according to Formula (6):

$$F = F_{WS} + F_D \tag{6}$$

where

F is the water footprint;

F_{WS} is the water scarcity footprint in H_2O-eq per unit of production;

F_D is the water degradation footprint expressed in H_2O-eq per unit of production.

Concerning the application of the ReCiPe impact assessment method, the individual endpoint results are normalized with European factors and weighted using the Hierarchist cultural perspective. This approach considers an equal weighting given to the current impacts on the area of protection “human health” and the current impacts on the area of protection “ecosystems”.

NOTE The application of alternative weighting procedures could impact on the absolute results and potentially change the relative importance of water consumed and water degraded in their contribution to the water footprint. Further details of the method are described in Ridoutt and Pfister (2013)[22].

For the simplified cereal cropping example described above, the water footprint profile is shown in Table 21.

Table 21 — Water footprint profile of cereal

Indicator	Characterized results (“pre-weighted results”)	Unit	Indicator result (“weighted results”)	Unit	Comment (calculation based on ReCiPe Version 1.07 - July 2012; http://www.lcia-recipe.net)
Water scarcity footprint	0,15	m^3 H_2O-eq / kg	0,15	m^3 H_2O-eq / kg	2 000 m^3 x (0,2/0,6) / 4 500 kg
Water degradation footprint associated with freshwater eutrophication [a]	0,000 074	species.a / kg	0,05	m^3 H_2O-eq / kg	0,407 ReCiPe points / 1,86 × 10^{-3} / 4 500 kg

[a] Since the only pollutant emitted is phosphate, the only impact category affected is freshwater eutrophication (i.e. no other impact categories, including human health, need to be assessed).

Following Formula (6), the water footprint resulting from the sum of indicator results for water scarcity footprint and water degradation footprint is 0,20 m^3 H_2O eq per kg crop product (at farm gate) (i.e. 0,15 plus 0,05).

6.13 Example M - Water footprint of packaging production as part of a life cycle assessment

6.13.1 Goal and scope

This example illustrates reporting of a water footprint profile as part of an LCA study.

This is an example of an LCA study of a specific packaging material The LCIA profile (Table 22) does not include the impact category “water availability” or “water scarcity”. Using the guidance of ISO 14046, this impact category is integrated into the LCIA profile of the original study in order to obtain a more comprehensive LCIA profile.

The functional unit is 1 t of packaging material.

This example also shows that most LCA study, even if not comprehensive, do contain non-comprehensive or comprehensive water footprint profile.

Table 22 — Impact indicator results for the LCA of a specific packaging material

Impact category (as used in the original LCA study)	**Units**	**Impact score** (per t of packaging material)
Climate change	t CO_2 eq	1,0
Energy non-renewable	GJ	1,05
Eutrophication	t N eq	$7,3 \times 10^{-4}$
Ecotoxicity	t 2,4-D eq	0,24
Acidification	t H^+ eq	$5,7 \times 10^{-4}$

6.13.2 Inventory

For the purposes of this example, the process to gather the inventory data of water consumption is not shown. The water consumption of packaging material is determined to be 113 m^3/t.

6.13.3 Impact assessment

The water scarcity footprint is calculated as the water consumption per functional unit multiplied by the characterization factor for the water scarcity of the location.

For the purposes of this example, the WULCA method (Boulay et al. 2016)[5] is used to evaluate the characterization factor and is identified as being 1.

The LCA results, after inclusion of the water scarcity footprint, are presented in Table 23.

Table 23 — Summary of results: water scarcity indicator as part of the original LCA

LCA profile	**Impact category**	**Units**	**Impact score** (per t of packaging material)
	Climate change	t CO_2 eq	1,0
	Energy non-renewable	GJ	1,05
Water footprint profile, as part of an LCA (assuming that here eutrophication, ecotoxicity and acidification only refers to water)	Eutrophication	t N eq	$7,3 \times 10^{-4}$
	Ecotoxicity	t 2,4-D eq	0,24
	Acidification	t H^+ eq	$5,7 \times 10^{-4}$
	Water scarcity footprint	m^3 H_2O eq	113

6.13.4 Interpretation

The water footprint assessment as part of a comprehensive product LCA study illustrated in this example, allows for an examination of the risks or impacts of water withdrawal for product manufacturing in terms of scarcity and other aspects, both present and future.

This application shows, as in the LCA study used in this example, how to enhance an existing LCA study with a water scarcity impact category.

6.14 Example N – Non-comprehensive water footprint of textile production

6.14.1 Goal and Scope

The intention of this example is to illustrate a method to calculate a water scarcity footprint considering seasonality and a non-comprehensive water degradation footprint.

The water scarcity footprint of the agricultural and fabrication unit processes is provided as the indicator result of the impact category water scarcity. The indicator is the result of the characterization of the inventory result by a local scarcity characterization factor reflecting seasonality of water scarcity. The location and time of freshwater consumption is taken into account for the cotton cultivation stage.

The non-comprehensive water degradation footprint is provided as the indicator result water degradation calculated by a distance to target approach.

The scope of the water footprint inventory analysis and impact assessment is the foreground system of the production of a pair of cotton jeans in southern Europe. The most relevant production stages from a water resources perspective are the cotton production stage and the spinning and weaving stages. In this example, only the foreground system of textile production is taken into account.

Figure 7 details the system boundary considered.

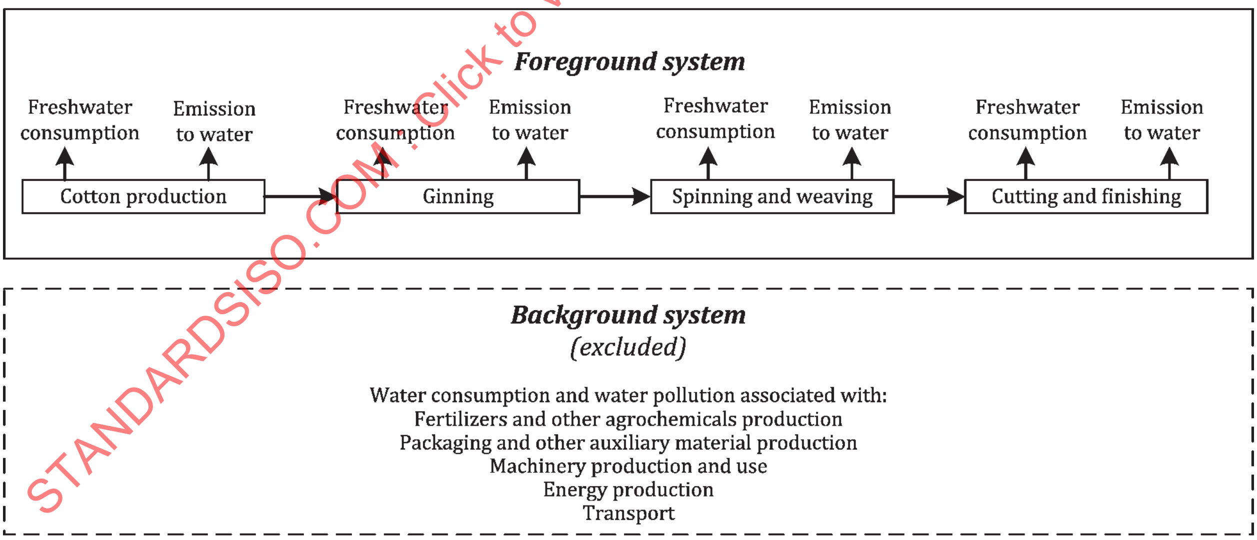


Figure 7 — System boundary

6.14.2 Inventory

Freshwater consumption of the cotton production stage is calculated by determining the monthly evapotranspiration of cotton ascribed to irrigation. Freshwater consumption is measured in each unit process of production. Ginning freshwater consumption is estimated as the humidity needed for safe fibre storage. The freshwater consumption of the spinning and weaving, and cutting and finishing stages are calculated from the balance between water inputs and outputs of the factory (Chico et al. 2013[38]).

The emissions to water in the cotton production stage is based on estimated excess nitrogen. The spinning and weaving, and cutting and finishing stages took place in a single production plant where effluents are collected before disposal to a municipal waste water treatment plant. Emissions to water are calculated based on COD.

In this example, a pair of jeans has a lint density of 0,29 kg per m^2 and requires 1,25 m^2 per pair on average, i.e. 0,36 kg of lint per pair of jeans.

Table 24 presents the inventory results per production stage expressed per kg of lint and per pair of jeans.

Table 24 — Inventory results for each inventory flow per production stage and textile

	Agricultural stage		Manufacturing stage			
	Cotton production		Ginning	Spinning and weaving	Cutting and finishing	Entire stage manufacturing
	Freshwater consumption (l)	Total nitrogen compounds, as N, to water (mg)	Freshwater consumption (l)	Freshwater consumption (l)	Freshwater consumption (l)	COD (mg)
Per kg lint	1 820,2	3,65	40,0	23,5	90,0	60
Per pair of jeans	653,5	1,3	14,4	8,4	32,3	22,5

6.14.3 Impact assessment

6.14.3.1 Water scarcity footprint

The characterization factor is the water scarcity index calculated according to Hoekstra et al. (2012) [11] per river basin and month as the ratio of total basin freshwater consumption to natural water availability.

Table 25 presents the results of the impact assessment associated with freshwater consumption in cotton production at a monthly level. The results represent the impact on water availability of cotton production in the area.

Table 25 — Water scarcity characterization factor, cotton production monthly freshwater consumption and cotton water scarcity footprint per month (calculated for the years 2005) in the basin studied (for a production of 17 kt of cotton)

Month	Water scarcity characterization factor	Monthly freshwater consumption of cotton production, for the entire basin (Mm^3 / month)	Cotton water scarcity footprint, for the entire basin (Mm^3 H_2O-eq / month)	Water scarcity footprint of a pair of jeans (l H_2O-eq / month)
1	0,05	0	0	0
2	0,13	0	0	0
3	0,20	0,56	0,11	2
4	0,48	2,91	1,40	29
5	1,32	4,64	6,15	128
6	3,43	6,69	22,96	483
7	4,94	6,91	34,15	716
8	5,48	5,8	31,80	671
9	5,23	3,23	16,89	363

Table 25 *(continued)*

Month	Water scarcity characterization factor	Monthly freshwater consumption of cotton production, for the entire basin (Mm^3 / month)	Cotton water scarcity footprint, for the entire basin (Mm^3 H_2O-eq / month)	Water scarcity footprint of a pair of jeans (l H_2O-eq / month)
10	4,36	0,45	1,96	41
11	2,64	0	0	0
12	0,33	0	0	0
Total	—	31,19	115,42	2 433

It is also possible to sum monthly values to provide a view of total cotton freshwater consumption and the water scarcity at the annual level. However, aggregation should be done carefully, since water consumption and water scarcity have a temporal dimension.

Table 26 presents the results of the impact assessment associated with freshwater consumption in jeans manufacturing at a monthly level.

Table 26 — Water scarcity characterization factor, jeans manufacturing monthly freshwater consumption and manufacturing water scarcity footprint per month (calculated for the years 2005) in the basin studied (for a manufacturing equivalent to 47 000 000 pairs of jeans)

Month	Water scarcity characterization factor	Monthly freshwater consumption of manufacturing in that basin (Mm^3 / month)	Jeans manufacturing water scarcity footprint (Mm^3 H_2O-eq / month)	Water scarcity footprint of a pair of jeans (l H_2O-eq / month)
1	0,05	0,22	0,01	0,01
2	0,13	0,22	0,03	0,01
3	0,20	0,22	0,04	0,02
4	0,48	0,22	0,11	0,05
5	1,32	0,22	0,29	0,14
6	3,43	0,22	0,76	0,36
7	4,94	0,22	1,09	0,52
8	5,48	0,22	1,21	0,58
9	5,23	0,22	1,15	0,55
10	4,36	0,22	0,96	0,46
11	2,64	0,22	0,58	0,28
12	0,33	0,22	0,07	0,04
Total	—	2,64	6,30	3,03

6.14.3.2 Water degradation footprint

The non-comprehensive water degradation footprint, used in this example, sometimes referred to as grey water footprint (Hoekstra et al. 2011[39]), is defined as the water volume needed for assimilating the load of pollutants given the ambient water quality standard in the receiving water body, calculated for each pollutant. The non-comprehensive water degradation footprint, used in this example is calculated according to Formula (7):

$$F_{\mathrm{D}} = \sum_i \left(\alpha_i \times E_i \right) \tag{7}$$

where

F_D is the non-comprehensive water degradation footprint, in l H_2O-eq;

α_i is the characterization factor for each E_i (l per mg) (α_i is assessed for each pollutant i as $\alpha_i = x / (C_{max} - C_{nat})$ with C_{max} being the ambient water quality standard in the receiving water body and C_{nat} the background natural concentration of the pollutant in the receiving water body);

E_i is the amount of pollutants emitted to water (mg).

The non-comprehensive water degradation footprint, used in this example, is determined by the pollutant that is most critical, that is, the one that is associated with the largest pollutant-specific degradation. In this example, nitrogen compounds emitted to water is used for the cotton production stage and COD for the fabrication stage.

Table 27 presents the non-comprehensive water degradation footprint results by production stage.

Table 27 — Non-comprehensive water degradation footprint results by production stage (average values)

	Agricultural stage (cotton production) Freshwater degradation associated with Nitrogen	Manufacturing stage (dominated by weaving) Freshwater degradation associated with COD
Characterization factor (l per mg)	121	0,001
Non-comprehensive water degradation footprint (l per kg lint)	443	0,08
Non-comprehensive water degradation footprint (l per pair of jeans)	159	0,03

6.14.4 Discussion

The example presented a particular application of a water footprint inventory analysis and water scarcity footprint and a non-comprehensive water degradation footprint of a particular product considering seasonality.

The example allows a local analysis of the impact of freshwater consumption associated with the production of jeans, identifying the places and months where this production poses a greater impact on the water resource.

6.14.5 Limitations

The non-comprehensive water degradation footprint as calculated in this example (termed grey water footprint in Hoekstra et al. 2011[39]), aims to estimate the pressure of a specific process on freshwater bodies in terms of their capacity to assimilate pollutants. However, it does not have the capacity to account for all the different aspects of water quality degradation. For example, pollutants are only taken into account when they are reflected in the ambient water quality standard.

The approach used in this example to assess the water degradation footprint uses a characterization model that has two specificities as compared to the more “traditional” life cycle assessment.

— It uses the ambient water quality standard as a proxy for assimilation capacity of freshwater bodies and for the environmental impact: this assumes that the ambient water quality standards are based and correlated to actual environmental impacts (i.e. that the ratio between the ambient water quality standard of two pollutants reflects the ratio between the environmental impact of those two pollutants). This is not always the case as some ambient water quality standard may be influenced by other factors than purely the environmental impacts. This limitation needs to be kept in mind when interpreting the results of this approach.

— It uses only the “dominant” pollutants in the characterization model. It means that it assumes that the environmental impacts are correlated with the pollutant being more demanding in terms of assimilation capacity of freshwater bodies (i.e. "reaching" first the ambient water quality standard), independently of the amount of other pollutants. It means, for example, that in a drainage basin where NO_3^- reaches first the ambient water quality standard as compared to PO_4^{3-} and glyphosate, an activity emitting 1 kg NO_3^-, 10 g PO_4^{3-} and 0,01 g of glyphosate, has the same potential impact as an activity emitting also 1 kg NO_3^- but only 2 g PO_4^{3-} and 0,001 g glyphosate. This assumption that only the "dominant" substance "counts" for the environmental impact is in contradiction with the more traditional life cycle impact assessment that accounts for cumulative impacts of different pollutants. Whether the approach presented in this example or the more traditional impact assessment is more correct is outside the scope of this document. However, the limitations associated with these assumptions need to be kept in mind when interpreting the results.

NOTE The approach using the P-limited and N-limited impact categories for water eutrophication is also based on the assumption that the impacts are linked to only the "dominant" pollutant; however, in that case both impact categories are presented together: this allows to not "loose" the "cumulative" view.

6.15 Example O – Non-comprehensive weighted water footprint of municipal water management

6.15.1 Goal and scope

This example illustrates calculation of a water footprint at midpoint and endpoint, and use of weighting to give a stand-alone indicator.

A water utility, located in a region A with relatively high water scarcity, provides a service that integrates drinking water production and distribution to users and waste water treatment before discharge to the environment.

The goal is to assess the water footprint of urban water cycle as:

— a comprehensive water footprint profile, presented at the level impact categories and areas of protection, integrating all relevant impacts related to water;

— a single value obtained after weighting.

The functional unit is the distribution of 1 m^3 of drinking water to users. This study includes direct water consumption and quality degradation generated through drinking water uses and also indirectly due to the consumption of energy and reagents at water and waste water treatment plants.

6.15.2 Inventory

Elementary flows are the river water withdrawal (#1) and the treated waste water discharge (#4) (Figure 8).

NOTE For simplicity, other flows such as losses in the domestic (or drinking) water distribution network (#2), the waste water collection network (#3) and the Reuse water distribution network, are not taken into account in this example.

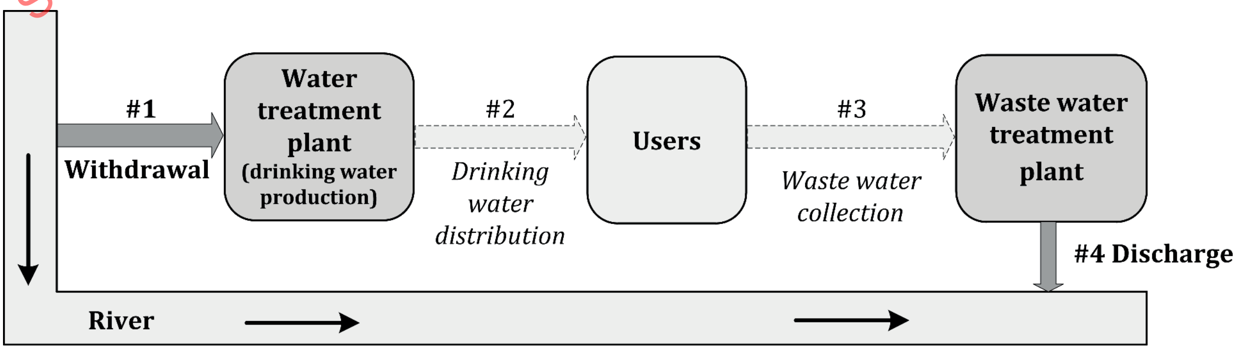


Figure 8 — Scheme of urban water cycle

Every year, 100 Mm^3 of drinking water are distributed. The waste water generated by the use of this drinking water is sent to the waste water treatment plant for treatment previous its discharge into the river. The data of the water footprint inventory for water-related flows are presented in Table 28. Data, relevant for water footprint assessment, are also collected for all the reagents or energy used for water and waste water treatment.

Table 28 — Collected data for the distribution of 1 m^3 of drinking water

	Description		Quantity	Unit
Input	River water withdrawal (#1)		1	m^3
Output	Treated waste water discharge (#4)		0,9	m^3
	Nitrogen compound	Ammonia	2	g
	Nitrogen compound	Nitrates	12	g
	Phosphorous	Phosphorous	2	g
	Hormones	Estradiol	1×10^{-5}	g
	Hormones	Ethinyl estradiol	1×10^{-5}	g
	Pesticides	Chloropyrifos	5×10^{-5}	g
	Pesticides	3-(3,4-dichlorophenyl)-1,1-dimethylurea	$2{,}2 \times 10^{-4}$	g
	Polycyclic aromatic hydrocarbons	Anthracene	$2{,}2 \times 10^{-4}$	g
	Polycyclic aromatic hydrocarbons	Fluoranthene	1×10^{-4}	g
	Pharmaceuticals	Erythromycin	1×10^{-4}	g
	Pharmaceuticals	Ibuprofen	3×10^{-4}	g
Reagent consumption	Reagent 1		0,010	kg
	Reagent 2		$1{,}0 \times 10^{-3}$	kg
Energy consumption	Electricity		0,072	kWh

NOTE For simplicity, the inventory is limited to the most relevant parameters regarding water quality (selected micropollutants) or treatment plant's life cycle (reagents, energy), but in practice it is recommended to be as comprehensive as possible in the water footprint assessment. The emissions indicated in Table 28 correspond therefore to the emissions associated with the full life cycle under study.

6.15.3 Impact assessment

6.15.3.1 Indicators

Indicators have been selected for different impact categories as well as the three area of protection and are summarized in Table 29.

Table 29 — Indicator and associated characterization model used

Type of indicators	Impact category	Characterization model	Area of protection	Characterization model
Consumptive water use	Water scarcity	Water scarcity index from Pfister et al. (2009)[7]	Ecosystems	Water deprivation effect to ecosystems from Pfister et al. (2009)[7]
			Human Health	Water deprivation effect to human health from Pfister et al. (2009)[7]
			Resources	Water deprivation effect to resources from Pfister et al. (2009)[7]
Water degradation	Freshwater eutrophication	ReCiPe (Goedkoop et al. 2009[21])	Ecosystems	ReCiPe (Goedkoop et al. 2009[21])
Water degradation	Marine eutrophication	ReCiPe (Goedkoop et al. 2009[21])		ReCiPe (Goedkoop et al. 2009[21])
Water degradation	Freshwater acidification	IMPACT 2002+ (Jolliet et al. 2003[15])		IMPACT 2002+ (Jolliet et al. 2003[15])
Water degradation	Marine acidification	Missing		Missing
Water degradation	Freshwater ecotoxicity	USEtox (Rosenbaum et al. 2008[17])		USEtox (Rosenbaum et al. 2008[17])
Water degradation	Marine ecotoxicity	Missing	—	Missing
Water degradation	Toxicity to Human	USEtox (Rosenbaum et al. 2008[17]) (see NOTE 2)	Human Health	USEtox (Rosenbaum et al. 2008[17])

NOTE 1 In this example, impacts from ionizing radiation, thermal release as well as other types of water body use (such as groundwater extraction or hydropower use of stream) have not been included.

NOTE 2 Following the scope of ISO 14046, whatever the approach used (i.e. midpoint or endpoint), the impact categories related to human toxicity (cancer, non-cancer, and from ionizing radiations) within the water degradation footprint only account for emissions reaching humans through either water emission or through air and soil emissions going to water and reaching humans, e.g. through water consumption, seafood consumption. In practice, impact assessment models may not always be able to do so. For example, in the default version of the USEtox model, which is used here, impacts on human health (from those three impact categories) associated with every fate and exposure pathway is accounted for and is therefore an overestimation of the impacts on human health from water degradation footprint. The model IMPACT World + (Bulle et al. 2016[16]) allows to take into account the fate of the contaminant in water, and hence only the relevant fraction to the water footprint.

6.15.3.2 Weighting step

Based on the indicators assessed, a weighed water footprint is calculated according to an adaptation of the Ridoutt and Pfister (2013) method[22] by Penru et al. (2014)[40] which permits the aggregation of the impacts of both consumptive and degradative water use into a single stand-alone indicator.

Concerning the application of the ReCiPe impact assessment method, the individual endpoint results are normalized with European factors and weighted using the Hierarchist cultural perspective. This approach considers an equal weighting given to the current impacts on the area of protection “human health” and the current impacts on the area “ecosystems”. ̈

NOTE The application of alternative weighting procedures could impact on the absolute results and potentially change the relative importance of water consumed and water degraded in their contribution to the water footprint.

The final result is expressed in litre of water equivalent (l H_2O-eq) as this is more meaningful for public communication. Conversion factors used to go from impact categories to weighed results are presented in Table 30.

Table 30 — Conversion factors used to go from impact categories to weighed results

	Degradative water use	Consumptive water use
Aquatic eutrophication	53	—
Aquatic acidification	$2,5 \times 10^{-2}$	—
Freshwater ecotoxicity	$1,0 \times 10^{-2}$	—
Human toxicity	$9,2 \times 10^{7}$ (cancer) $2,2 \times 10^{7}$ (non-cancer)	—
Water scarcity	—	1,7

6.15.4 Interpretation

Water footprint profiles are presented in Table 31.

Table 31 — Impact assessment results

	Impact score	Unit
Aquatic eutrophication [a]	$3,8 \times 10^{-4}$	kg P eq / FU
Aquatic acidification [a]	$1,1 \times 10^{-4}$	kg SO_2 eq / FU
Freshwater ecotoxicity [a]	0,2	CTU_e / FU
Human toxicity [a]	$2,1 \times 10^{-11}$	CTU_h / FU
Water scarcity [a]	$1,9 \times 10^{-3}$	m^3 H_2O eq / FU
Ecosystem quality [b]	$8,9 \times 10^{-3}$	PDF.m^2.a / FU
Human health [b]	$7,2 \times 10^{-11}$	DALY / FU
Resources [b]	$5,1 \times 10^{-5}$	MJ / FU

[a] At the level of impact categories, expressed in midpoint units.

[b] Area of protection, expressed in endpoint units.

The water scarcity footprint and water degradation footprint are calculated by aggregation and weighting, as presented before. Finally, the water footprint can be expressed as a single, stand-alone indicator (Table 32).

NOTE According to ISO 14044:2006, 4.4.5, weighting cannot be used in LCA studies intended to be used in comparative assertions intended to be disclosed to the public.

Table 32 — Water scarcity footprint, water degradation footprint and (weighed) water footprint of the baseline

	Water scarcity footprint	Water degradation footprint	Weighted water footprint
	l H_2O-eq / m^3 water distributed to users		
Baseline	32	227	259

In this example, the water degradation footprint is more important than the water scarcity footprint. These results suggest that in order to reduce the weighted water footprint of this urban water cycle, improvement should be made to the discharged water quality.

In order to reduce the water degradation footprint, a tertiary treatment of the waste water is implemented at the waste water treatment plant. It achieves better removal of nutrient and micropollutants whereas it increases the consumption of reagents and energy (Table 33).

Table 33 — Collected data for the distribution of 1 m^3 of drinking water after tertiary treatment implementation

	Description		Quantity	Unit
Input	River water withdrawal (#1)		1	m^3
Output	Treated waste water discharge (#4)		0,9	m^3
	Nitrogen compound	Ammonia	0,5	g
	Nitrogen compound	Nitrates	2	g
	Phosphorous	Phosphorous	0,5	g
	Micropollutants		Not detected	
Reagent consumption	Reagent 1		0,010	kg
	Reagent 2		$1,9 \times 10^{-3}$	kg
Energy consumption	Electricity		0,1	kWh

After waste water treatment improvement, both water degradation footprint and the weighted water footprint are reduced by 75 % and 66 %, respectively (Table 34). Based on these results, this example illustrates the relevance of an initial baseline to evaluate the impact of process modifications on water footprint.

Table 34 — Water scarcity footprint, water degradation footprint, and weighed water footprint after waste water treatment plant improvement and comparison to the baseline

	Water scarcity footprint	Water degradation footprint	Weighted water footprint
	l H_2O-eq / m^3 water distributed to users		
Baseline	32	226	259
After improvement	32	56	89
Compared to the baseline	No change	−170 (−75 %)	−170 (−66 %)

This example illustrates the use of several levels of water footprint indicators for non-comprehensive and weighted water footprint. It helps to prioritize actions for water footprint reduction. The water footprint allows to quantify the influence associated with the improvement.

The approach could be improved by using:

a) a comprehensive list of impact categories to assess the water degradation;

b) monthly scarcity characterization factors.

It also reflects overall performance based on annual values, but could be applied at a daily level to take into account possible variation on water quality.

NOTE The application of alternative weighting procedures could impact on the absolute results and potentially change the relative importance of water consumed and water degraded in their contribution to the water footprint as well as the relative importance of impacts to human health and ecosystem within the water degradation footprint.

6.16 Example P – Non-comprehensive water footprint of a company producing chemicals (organization)

6.16.1 Goal and scope

This example illustrates the calculation of direct water scarcity footprints and non-comprehensive direct water degradation footprints for an organization comprising two sites.

The goal of this example is to quantify the corporate sites' water scarcity footprint and different types of water degradation footprints of a chemicals producing company, where the assessed activities of the facilities are owned by the chemical company.

It will be outlined how the different corporate sites water footprints can be calculated. In the degradation section, the following are calculated and reported for each corporate site:

— eutrophication water degradation footprint;

— heavy metal water degradation footprint;

— organic substances water degradation footprint.

The chemicals company operates many production sites worldwide and produces thousands of products for different applications. The organization has the financial and operational control over the facilities. The water footprint of the organization therefore accounts for the activities under its control.

NOTE The following formulation is also sometimes used: "It accounts for the 100 % of the potential environmental impacts related to water of its operations". This formulation is not used in this document in order to avoid mixing with the concept of comprehensiveness when talking about "100 % of the potential environmental impacts".

The reporting unit is the annual production of the company, produced on different sites.

This example focuses on the gate-to-gate boundary, but could be combined with water footprint results associated with upstream activities in order to generate the cradle-to-gate water footprint of the company. The boundary can be modified depending on the scope and standard with which the water footprint of organization needs to comply.

6.16.2 Inventory

The company collected data on annual water inputs and outputs from each of the facilities, in order to determine the direct water consumption. That includes cooling processes, electricity production, waste water treatment facilities and waterworks which are owned and operated by the company.

The annual freshwater consumption from a facility is the difference between the freshwater input and the waste water discharge. Indirectly, the water content of the products are included if this water content is generated in the boundary of the reporting company.

The annual freshwater input is determined by quantifying the water which is supplied via water pipes from external suppliers and from site-owned sources.

The annual freshwater discharge is determined as the volume of water which leaves the plant in sewage pipes minus the volume of storm water which flows through those pipes. Water evaporation from the area of the plant is not considered as it is assumed that the same volume of water evaporated before the plant is built.

The water use of those sites is assessed with the local water scarcity index (Berger et al. 2014[12]). Only those two sites can be summarized to an aggregated water footprint because averaging of freshwater consumption on the inventory level, as used for other LCI data, is not permitted for the determination of the water footprint (see ISO 14046).

Most of the water is used for cooling of reactions and is discharged to the same water basin afterwards. A high amount of water is used several times for cooling before it is discharged back to the basin. Losses of water are linked to direct integration of water into products, losses by evaporation for electricity production, steam production and in the condensation process of water after cooling in the different facilities of a site. The two sites produce their own electricity and steam on-site, so these water uses and losses are considered as well.

Additionally different water degradation footprints are calculated by collecting data for emissions to water of heavy metals, nitrogen and organic substances expressed in COD. Data for the assessment of the company were collected from every site to introduce them into the average figures. Though the geography may be relevant for the impact to the environment related to degradation, in practice, for the sake of simplification, aggregation is often done at the inventory level. It is considered, that no specific protection areas are linked with the emissions.

6.16.3 Impact assessment

6.16.3.1 Direct water scarcity footprint

The annual direct water scarcity footprint of a plant n is calculated as the annual direct freshwater consumption of this facility (i.e. the quantity of water which “disappears” by evaporation, integration into solid products or waste or direct release into the sea) multiplied by the characterization factor for water scarcity of the location where the facility operates.

The direct water scarcity footprint parameters of two sites with different water scarcity indices are shown in Table 35.

Table 35 — Direct water scarcity footprint of the two sites belonging to the organization (for the year 2013)

	Fresh water input Mm^3	Total water discharge Mm^3	Fresh water consumption Mm^3	Water scarcity index of the region considered	Water scarcity footprint, total Mm^3 H_2O-eq
Site 1, region 1	1 248	1 222	26	0,1	2,6
Site 2, region 2	232	227	5	1	5,0
Total	—	—	—	—	7,6

The direct water scarcity footprint of all facilities of the company from gate-to-gate is 7,6 Mm^3 H_2O-eq per year.

To generate a cradle-to-gate water scarcity footprint, all purchased products, energy, and all external services need to be included, after consideration of the cut-off criteria. Therefore, much more data are needed from suppliers, including for every single product, energy carrier, etc., that is purchased.

6.16.3.2 Non-comprehensive direct water degradation footprint

Water that has been used for washing operations, quenching, reaction-stopping, work-up, etc., during the production of chemicals, often contains pollutants. The waste water is treated after use and is released to the same drainage basin as it is withdrawn. The water has a good quality after the treatment, but some pollutants remain. This reduces the quality of water compared to freshwater and results in a water degradation footprint.

The impact assessment can be made with different methods. In this example, the assessment of non-comprehensive water degradation is carried out by means of the “critical water volume (CWV)” model (Powell et al. 1995[41], Schmidt et al. 1992[42]). Only emissions to water are considered - air or soil emissions from the sites with effects on water are not accounted for - therefore the water degradation footprint is only an assessment of a non-comprehensive water degradation.

For selected pollutants that enter the water, the theoretical water volume required to dilute the pollutant to the statutory limit value (critical load) is determined. The volumes calculated for each pollutant are added up to yield the non-comprehensive water degradation footprint.

The factors for calculating the non-comprehensive water degradation footprint are shown in the Table 36. The requirements that are made on sewage at the point of discharge to surface water, listed in the appendices to the German Waste Water Regulation, are the basis for the factors. In general, region specific factors are used for the different sites. Because they are not available for all regions, the factors of the German Waste Water Regulation are used in this example, and are presented for illustration only.

These limits are generally based on the relevance of the emitted substance for the environment; in some cases, technical issues are taken into account in establishing the regulation. The more critical a pollutant is due to its environmental effect in the aquatic system, the higher the relevant characterization factor. Based on scientific criteria, the potential of different pollutants to harm the environment is assessed and expressed in the characterization factor. Other impact assessment systems can be chosen and the factors shown in this example can be replaced if there is a scientific sound basis for them to avoid misleading information.

The non-comprehensive water degradation footprint is calculated according to Saling et al. (2002)[23] with Formula (8).

$$F_D = \sum_i \left(\alpha_i \times E_i\right) \tag{8}$$

where

F_D is the non-comprehensive water degradation footprint, expressed in litres H_2O-eq;

α_i is the characterization factor for each E_i which can be obtained for each pollutant i;

E_i is the amount of pollutants emitted to water.

Table 36 — Characterization factors for the pollutants

Pollutant to water	**Requirement on waste water** (mg/l) (Appendix 22 to German Waste Water Regulation)	**Characterization factor** (l H_2O-eq / mg)
Organic substances	75	0,013
N total	13	0,077
Hg	0,001	1 000
Cd	0,005	200
Cr	0,05	20
Zn	0,2	5
Cu	0,1	10
Ni	0,05	20
Pb	0,05	20
Sn	0,2	5
Other heavy metals	2	0,5

Often parameters of pollutants are collected as aggregated figures. This is true in this example for heavy metals. In that case the most critical figure is chosen in a conservative approach. This calculation shows a high importance for the heavy metals subsequently (Table 37 and Table 38).

For a better interpretation of the results and the assessment of the variability, a scenario analysis is needed to show how the system changes depending on what actual metals are part of the heavy metals category. In this scenario, though both sites are not in the same region, the same requirements on waste water are assumed.

Table 37 — Corporate sites non-comprehensive water degradation footprint with conservative characterization factors for heavy metals

Location	Pollutant to water	Emission (t/a)	Requirement on waste water (mg/l = g/m³) (Appendix 22 to German Waste Water Regulation)	Characterization factor (m^3 H_2O-eq / g)	Degradation water footprint (Mm^3 H_2O-eq / a) (considering 10^6 to go from t to g and 10^{-6} to go from m^3 to Mm^3)
Site 1	Organic substances (COD)	6 500	75	0,013	87
	N total	1 230	13	0,077	95
	Heavy metals	14	0,001	1 000	14 000
Site 2	Organic substances (COD)	1 344	75	0,013	18
	N total	172	13	0,077	13
	Heavy metals	2	0,001	1 000	1 500
Total	Organic substances (COD)	7 730	150	0,013	105
	N total	1 402	26	0,077	108
	Heavy metals	16	0,002	1 000	15 500
	Total	—	—	—	15 713

Table 38 — Corporate sites non-comprehensive water degradation footprint with lower characterization factors for heavy metals

Location	Pollutant to water	Emission (t/a)	Requirement on waste water (mg/l = g/m³) (Appendix 22 to German Waste Water Regulation)	Characterization factor (m^3 H_2O-eq / g)	Degradation water footprint (Mm^3 H_2O / a) (considering 10^6 to go from t to g and 10^{-6} to go from m^3 to Mm^3)
Site 1	Organic substances (COD)	6 500	75	0,013	87
	N total	1 230	13	0,077	95
	Heavy metals	14	0,05	20	280
Site 2	Organic substances (COD)	1 344	75	0,013	18
	N total	172	13	0,077	13
	Heavy metals	2	0,05	20	30
Total	Organic substances (COD)	7 730	150	0,013	105
	N total	1 402	26	0,077	108
	Heavy metals	16	0,002	20	320
	Total	—	—	—	533

6.16.4 Interpretation

Different types of water footprints can be calculated. Depending on the goal and scope of such a study, a water scarcity footprint as well as a non-comprehensive water degradation footprint can be obtained by using data that companies report in their annual reports or in other publication frameworks. In this example only the impacts directly associated with site water consumption or some site emissions are accounted for.

The non-comprehensive direct degradation water footprints presented here describe non-comprehensive water degradation of the company related to direct emissions to water only. In order to make the direct water degradation footprint complete, the water degradation footprint associated with air and soil emissions affecting water would need to be calculated.

6.17 Example Q – Water scarcity footprint of an aluminium company (organization)

6.17.1 Goal and scope

This example illustrates calculation of the direct and indirect water scarcity footprint of an organization comprising a number of different facilities throughout the supply chain.

The goal of the study is to determine the water scarcity footprint of an organization, i.e. an aluminium company which owns four bauxite mines, three alumina refiners and eight aluminium smelters, but does not own or control plants for semi-finished products. The organization has the financial and operational control over the facilities included in this study. The water footprint of the organization therefore accounts for the activities under its control.

An additional goal of the study is to determine the direct and indirect water scarcity footprint of the primary aluminium which the company supplies.

The overall activity of the company is to produce bauxite, alumina and primary aluminium ingots. The reporting unit is the annual production of the company.

Two different boundaries are considered, i.e. the boundary for the organization and the cradle-to-gate boundary for the organization, see ISO 14046:2014, Figure A.1. As shown in Figure 9, the cradle-to-gate system includes the supply of the most important materials and energy. The term “cradle-to-gate” means that the further processing, use and end-of-life stages of specific aluminium products are excluded from the system.

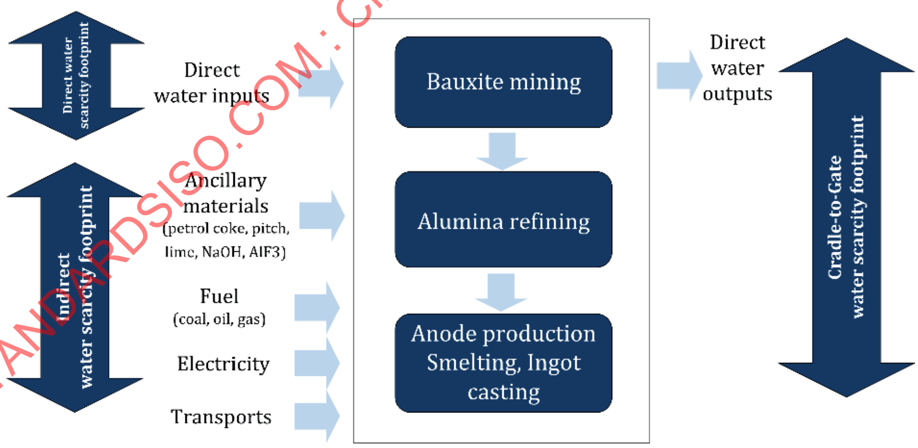


Figure 9 — Direct, indirect and cradle-to-gate water scarcity footprint (WSF) of an aluminium company

The annual production of the smelters is 2,41 Mt of primary aluminium for which 4,7 Mt of alumina are needed. The alumina refiners of the company produce 8,7 Mt of alumina annually, from which they sell 4,7 Mt to the own smelters and 4,0 Mt to third-party companies.

For the annual production of the refiners of 8,7 Mt alumina, 25,3 Mt of bauxite are needed. The mines of the company produce, annually, 30 Mt of Bauxite, from which they sell 25,3 Mt to their own refineries 4,7 Mt to third-party companies.

Consequently, the reporting unit of the aluminium company is the supply of 2,41 Mt of primary aluminium, 4,0 Mt of alumina and 4,7 Mt of bauxite.

6.17.2 Inventory

The company collected data from each of the plants on annual water inputs and outputs, in order to determine the direct water consumption. Furthermore, data on annual ancillary material consumption, fuel and electricity consumption and transports are collected to determine the indirect water scarcity footprint.

The annual freshwater consumption includes the difference between the freshwater input and the water discharge and, for bauxite mines, also includes the water content of the shipped bauxite.

The freshwater input is determined by quantifying the water which is supplied via water pipes by external suppliers and from site-owned ground water sources or from rivers and lakes.

NOTE 1 Water coming from external suppliers is part of indirect water footprint. In this example, water consumption of external water supply systems has been neglected.

The water discharge is determined as the volume of water which annually leaves the plant in sewage pipes minus the annual volume of storm water which flows through those pipes. Water evaporation from the area of the plant is not considered as it is assumed that the same volume of water had evaporated before the plant had been built.

NOTE 2 Water going to sewage pipes managed by external company is part of indirect water footprint. In this example, water consumption of external sewage plant has been neglected.

It has been decided to use the method of Pfister et al. (2009)[7] as a source for the characterization factors. For each site the local water scarcity index (used as characterization factor) is determined using Pfister et al. (2009)[7].

As averaging includes aggregation, "conventional" averaging of freshwater consumption on the inventory level, as used for other LCI data, is not permitted for the determination of the water footprint, if the relevant sites are located in areas with different water scarcity (see ISO 14046:2014, 5.3.2). Therefore, for the purpose of this study, no averages of the water consumption of the aluminium plants are calculated.

6.17.3 Impact assessment

6.17.3.1 Direct water scarcity footprint

In this example, the annual direct water scarcity footprint of each plant is calculated as the annual freshwater consumption (i.e. the quantity of water which has evaporated, integrated into sold products or waste or directly released into the sea,) multiplied by a local characterization factor. The local characterization factor is the water scarcity index of the location where the plant operates (being the water scarcity index associated with the method of Pfister et al. (2009)[7] for that location divided by the average global water scarcity index associated with the method of Pfister et al. (2009)[7], i.e. 0,6).

The direct water scarcity footprint parameters of the different bauxite mines, alumina refiners and smelters of the aluminium company are shown in Table 39, Table 40, and Table 41.

Table 39 — Direct water consumption and direct water scarcity footprint of bauxite mines

Mine	Local waster scarcity index	Shipped bauxite Mt/a	Water contained in bauxite Mm^3/a	Total fresh water input Mm^3/a	Total water discharge Mm^3/a	Fresh water consumption Mm^3/a	Direct WSF, total Mm^3 H_2O-eq/a	Direct WSF per t of bauxite m^3 H_2O-eq/t
Mine 1	0,013	13,0	1,3	2,4	1,1	2,6	0,05	0,004
Mine 2	0,24	8,6	0,7	1,1	0,0	1,8	0,72	0,083
Mine 3	0,13	2,5	0,3	0,9	0,3	0,9	0,20	0,081
Mine 4	0,06	5,6	0,5	3,2	1,6	2,1	0,21	0,038
Total or Average		30	—	—	—	—	1,18	0,040

Table 40 — Direct water consumption and direct water scarcity footprint of alumina refiners

Refiner	Local waster scarcity index	Shipped alumina Mt/a	Freshwater input Mm^3/a	Water discharge Mm^3/a	Water consumption Mm^3/a	Direct WSF Mm^3 H_2O-eq/a	Direct WSF per t of alumina m^3 H_2O-eq/t
Refiner 1	0,01	4,5	17,8	6,8	11,0	0,2	0,04
Refiner 2	0,34	1,7	7,6	1,2	6,4	3,6	2,13
Refiner 3	0,16	2,5	26,1	12,8	13,3	3,5	1,42
Total or Average		8,7	—	—	—	7,4	0,85

Table 41 — Direct water consumption and direct water scarcity footprint of aluminium smelters

Plant name	Local waster scarcity index	Shipped aluminium Mt/a	Freshwater input Mm^3/a	Water discharge Mm^3/a	Water consumption Mm^3/a	Direct WSF Mm^3 H_2O-eq/a	Direct WSF per t m^3 H_2O-eq/t
Smelter 1	0,010	0,23	0,80	0,67	0,13	0,002 2	0,009
Smelter 2	0,069	0,42	1,20	0,79	0,41	0,047	0,112
Smelter 3	0,032	0,15	0,30	0,17	0,13	0,006 8	0,046
Smelter 4	0,100	0,09	0,11	0,06	0,05	0,008 3	0,093
Smelter 5	0,011	0,48	3,60	2,10	1,50	0,029	0,059
Smelter 6	0,051	0,35	1,90	1,35	0,55	0,047	0,134
Smelter 7	0,014	0,52	2,90	1,89	1,01	0,023	0,044
Smelter 8	0,022	0,17	3,20	2,60	0,60	0,022	0,127
Total or Average		2,41	—	—	—	0,185	0,077

The direct water scarcity footprint of the company is 8,7 Mm^3 H_2O-eq/a, where:

— the bauxite mines contribute to 1,18 Mm^3 H_2O-eq/a;

— the alumina refiners contribute to 7,4 Mm^3 H_2O-eq/a;

— the smelters contribute to 0,18 Mm^3 H_2O-eq/a.

6.17.3.2 Indirect water scarcity footprint

In order to determine the indirect WSF of the different plants of the companies, data about the consumption of ancillary products and energy of the bauxite mines, the refiners and the smelters are collected. For each of those inputs, the WSF data are determined via a data provider.

Special consideration is given to the electricity supply of the smelters. Each smelter reported its electricity consumption and the source of electricity (dedicated power plant, national grid or regional grid). Then for each dedicated power plant the WSF per MWh is determined. For those smelters which got the electricity from a national or a regional grid, the WSF per MWh is determined by:

— selecting a representative number of power plants from this grid;

— determining the total WSF and the total electricity production, plant-by-plant;

— dividing the total WSF by the total electricity production of these power plants.

The result is shown in Table 42.

Table 43, Table 44, and Table 45 show the calculation of the indirect WSF of the bauxite mines, the alumina plants and the smelters.

NOTE The WSF associated with the ancillary materials, fuels and electricity is calculated as the production weighted WSF of the different suppliers in the background. However, this work is done in and by the background database supplier and is used as a generic information.

Table 42 — Calculation of the annual WSF of the electricity supply of the aluminium smelters

Plant name	**Shipped aluminium**	**Electricity consumption**		**WSF of electricity**	**Annual WSF of electricity**
	Mt/a	MWh/t	MMWh/a	m^3 H_2O-eq/MWh	Mm^3 H_2O-eq/a
Smelter 1	0,23	14,5	3,3	0,23	0,77
Smelter 2	0,42	13,8	5,8	0,16	0,93
Smelter 3	0,15	15,1	2,3	0,69	1,56
Smelter 4	0,09	15,6	1,4	0,52	0,73
Smelter 5	0,48	12,9	6,2	0,32	1,98
Smelter 6	0,35	14,8	5,2	0,12	0,62
Smelter 7	0,52	14,0	7,3	0,09	0,66
Smelter 8	0,17	13,7	2,3	0,85	1,98
Total or Average	2,4	14,0	33,8	0,3	9,2

Table 43 — Direct and indirect WSF of bauxite mines

Type of input	**WSF per type of input** [a]		**Input per t of bauxite**		**Total production of bauxite mines**	**WSF**
	Amount	Unit	Amount	Unit	Mt	Mm^3 H_2O-eq
Heavy oil	2,0	m^3 H_2O-eq/t	0,20	kg/t	30	0,012
Diesel oil	3,1	m^3 H_2O-eq/t	0,30	kg/t	30	0,028
Electricity	0,35	m^3 H_2O-eq/MWh	0,90	MWh/t	30	0,009
					Total indirect WSF	0,05
					Total direct WSF of bauxite mines (see Table 39)	1,18
					Total direct and indirect WSF	1,23

[a] This table uses simplified values which are not intended to be reproduced.